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Water-Supply and Irrigation Paper No. 72 Series L, Quality of Water, 3

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

SEWAGE POLLUTION

IN THE

METROPOLITAN AREA

NEAR NEW YORK CITY

AND

ITS EFFECT ON INLAND WATER RESOURCES

BY

MARSHALL ORA LEIGHTON

GOVERNMENT PUBLICATIONS
OCT 15 1938
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WASHINGTON
GOVERNMENT PRINTING OFFICE
1902

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WINSTON, N. C.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., May 24, 1902.

SIR: I have the honor to transmit herewith a manuscript by Mr. Marshall O. Leighton, relating to sewage pollution in the metropolitan area, and to request that it be published in the series of Water-Supply and Irrigation Papers. In an investigation of the water resources of the country it becomes necessary in the thickly settled portions to give consideration not merely to the quantity of water and its fluctuations, but also to the quality, and to the changes that are taking place owing to the presence of various industries.

The best methods of utilizing the water resources of the country are dependent not only upon geologic and topographic features, but also upon what has been termed cultural conditions, the latter embracing all of the changes brought about by man. The accompanying discussion by Mr. Leighton relates to a portion of the most thickly settled part of the United States, and shows that water resources may be so misused that streams which in their natural condition were useful and attractive may be rendered obnoxious and made sources of loss to the community.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEWAGE POLLUTION IN THE METROPOLITAN AREA NEAR NEW YORK CITY AND ITS EFFECT ON INLAND WATER RESOURCES.

By Marshall O. Leighton.

NORMAL WATERS.

In a primeval country, undisturbed by the advance of civilization, where there are no houses, barns, or factories, the water that flows from a drainage basin may be said to be normal. This, however, does not mean that the water is chemically pure. The water of precipitation or rainfall, which is the origin of all surface waters, takes three courses, the proportion carried along each depending upon many physical characters and conditions. There is, first, that which is evaporated or absorbed by vegetation; second, that which runs off the ground directly into water courses; and third, that which sinks into the ground and reappears in various well-known ways after having filtered through the earth.

The character of the water is markedly influenced by the ingredients which it takes up along these courses, and therefore chemically pure water is seldom found in nature. Water that runs along the earth's surface directly into natural water courses carries in suspension a large quantity of fine particles which lie in its way—vegetable matter in a state of complete disintegration, organic matter in various stages of oxidation, minute particles of sand and mineral matter from the earth, and large quantities of silt. On the other hand, water that sinks into the ground leaves behind, in the majority of cases, these suspended particles, but when it reappears it carries in solution the soluble mineral constituents of the earth through which it has passed, and, if it then contains any dissolved organic matter it is usually in an advanced state of oxidation. Water thus discharged from drainage areas is by no means uniform in composition, nor is it of the same nature in the same area during a series of examinations. Run-off water varies in character according to the amount of precipitation, the

season of the year and consequent state of vegetation, the extremes of temperature, the nature and slope of the surface of the land, and many other physical conditions, varying familiarly from season to season. During the season of copious rains it is observed that water from a drainage area carries along more sediment than during seasons of normal precipitation, and analysis would show that the organic matter contained in the water is in larger proportion. At the close of the warm season, during which vegetation has been flourishing, there is much less decayed and dried vegetable matter to be carried along than during the spring season, after the winter has destroyed the tender growth of the previous summer. Again, during the warm season there is a larger proportion of precipitation absorbed by vegetation and evaporated. The season is also a factor in determining the condition of water in countries in which snow covers the ground for a part of the year. During the time of snow the water which during warm seasons would be immediately diverted to its accustomed channels is retained upon the surface of the earth, to be evaporated by prevailing winds or to be melted quickly upon the approach of spring.

The slope and the nature of the surface of the land are important factors in determining the character of surface waters. Where surfaces are steep and smooth a large proportion of water runs directly into streams, and with it a great amount of sediment, while upon most flat surfaces nearly all the precipitation not directly evaporated sinks into the ground. Between the steep, smooth surfaces and the flat ones there are many gradations, each having its effect upon the final content of run-off water.

Distance from the ocean is another factor influencing the character of water. This has been the subject of an extended series of investigations by the Massachusetts State board of health, and later by other bodies, both corporate and private. It is found that the amount of chlorine is highest at coast points, and as we recede farther and farther inland the proportion in normal waters grows correspondingly smaller, so that it is possible to trace upon the map of a country the lines of uniform normal chlorine in much the same manner that lines of equal altitude are traced upon a topographic map.

The state of preservation of the forests of a country exerts an influence of great importance upon the character of surface waters and upon the flow of streams. In the absence of trees there is less absorption of rain water by the ground and a correspondingly larger proportion is carried directly into the water courses with a greater amount of sediment, so that a drainage area that has been largely denuded of trees is subject to greater variation of stream flow and more frequent freshets than is an area that is in large part covered by forests. On denuded areas there is less evaporation, and ultimately the whole character of the surface may be so changed by loss

of vegetation and extensive erosion that the immediate run-off water may comprise almost the entire precipitation.

Having reviewed the more important conditions and influences that affect the character of normal water, let us consider the economic value of water to the community. Intercepted and stored in reservoirs it has become indispensable to large communities for domestic and manufacturing uses; from prehistoric times large rivers have been used as avenues of transportation; as motive power water has been used for ages; vast harvests of ice are gathered from the surface of Northern rivers; in arid countries water finds extensive use in irrigation; it may be the source of food supply through fisheries, and its presence in a country is valuable from a purely æsthetic point of view, lakes and fountains forming a natural nucleus for parks, resorts, and places of rest and recreation.

POLLUTED WATERS.

When, however, man makes his abode in any area and carries on his normal life, the water draining that area soon assumes characters which it had hitherto not possessed. It now contains the products of excretions of man and of the domestic animals that accompany him, and the amount of change in the character of the water depends entirely upon the number of people and their pursuits. In the beginning pollution is indirect, but with social and commercial progress come modern improvements, and eventually the public sewer is laid to the nearest and most convenient body of water. This is the natural course, and in inland municipalities there may be developed in the course of time a system of sewerage conducting such a volume of city waste that the largest river on the globe can not dilute it sufficiently to disguise its presence. Let us consider briefly whether water so polluted can be applied to all of the uses to which normal waters have been found applicable.

Many American cities have been taught by dear experience that it is fatal to provide polluted waters for household purposes. Lowell and Lawrence, Newark and Jersey City, Albany, Pittsburg, Louisville, Cincinnati, and many other cities have profited by that experience. Philadelphia has just shaken off the lethargy of decades and is now preparing to filter the refuse of municipalities on the upper Schuylkill and Delaware. Other cities have their lesson yet to learn, but each will probably learn it only when its group of mourners has become large enough to demand attention. With childlike faith the city of Albany, reassured by the advice of an eminent chemist, established its water intake in the cesspool of the Hudson. Yet after a few years, during which many lives were lost in the ravages of water-borne disease, it constructed one of the most extensive filters in the

country, at a cost of half a million dollars. He who says that a polluted river will purify itself in the course of several miles reckons with an unknown force which will probably fail him at the critical time.

The same conditions and statements apply to ice. Although recent work seems to show that the germs of typhoid fever do not remain intact in ice as long as was formerly supposed, there is yet but little evidence obtained concerning the bacteria of other water-borne diseases. Irrespective of disease organisms, the use of ice from polluted waters in our houses and markets is abhorrent and will not be tolerated.

As a rule, the presence of pollution in water used for irrigation is not a detriment. On the contrary, it may be an aid to vegetation, although the manurial value of sewage is not so great as is popularly supposed.

The use of water for power is not usually affected by pollution, although in some cases mill ponds have become grievous nuisances on account of the storage of pollution from a municipality above. In certain kinds of manufacturing, however, pure water must be used, and in such cases the use of polluted water from a neighboring stream is prohibited, so that an added expense is necessitated for another supply and the value of the near-by stream is diminished.

A single stream very seldom—almost never—embraces all of the uses enumerated above. If the waters are navigable to any extent there can be no power sites, nor can the "raw" water be used for public supply, and only seldom is the ice which it bears a wholesome product. If, on the other hand, waters are to be conserved for power or for public supply, it will be impossible to use them for traffic. If a stream which is not navigable is polluted, it may be, if the pollution be extensive, that the water will be rendered unfit for any purpose whatever; for, transportation or ice cutting being precluded by the physical conditions, we have only irrigation, power, and public supply remaining. Of these three the last may be entirely cut off, the second may be modified, and only the first may remain practically intact. As irrigation is important only in the dry areas of the West, this asset does not apply in the remainder of the country, and so we find that in many cases the entire value of a stream may be lost through pollution.

Extensive pollution unfits a river for a nucleus for park areas. Deposits of filth upon the banks of streams make noxious odors and render such places undesirable as dwelling sites. The value of property is impaired, the neighborhood is shorn of desirable population, and places that were once fair to look upon may become, by reason of sewage pollution, famous only for foul odors and unpleasant associations.

The consideration of such matters is very familiar in treatises on

questions involving public health. It has been conceded that, from a general hygienic standpoint, no stream should be polluted with sewage. It is, however, the purpose of this paper to consider the matter from a standpoint of diminution of natural resources with special reference to the rivers in "the metropolitan area," comprising northern New Jersey, southern New York, and the western part of Massachusetts. It is proposed to take into account the water resources of this section and to show, as closely as available information will permit, the loss which has come about by reason of river pollution. This part of the United States has become the metropolitan area chiefly because of its natural resources, both maritime and inland. Among these sources of economic supremacy the value of the inland waters stands in the front rank.

The consideration of financial loss due to sewage pollution of streams in this area becomes, therefore, of immediate importance; and as we shall enumerate in the following pages the expenditures made necessary by this discredited practice, it is possible that we shall find sewage pollution not only an agency most destructive to human life, but one of the most far-reaching drains upon human wealth that has yet been considered. In addition to the mere question of existing pollution there is the problem of abatement or prevention, which is receiving consideration in many States under authority granted by legislative enactment. This method of consideration may serve admirably in the several States, but what of interstate pollution? State boundaries in the eastern part of this country are so closely set that instances of interstate grievance are numerous. A municipality made miserable by polluted water from another State is deplorably helpless to obtain remedy. There is no national authority over such matters.

RARITAN RIVER.

The Raritan River is the largest in New Jersey, and the second in economic importance. The drainage area—1,105 square miles in extent—is of a mixed type, having 275 square miles of highland area, 100 square miles of sandy plain, and the remainder of red sandstone. Budd Lake, 1½ miles long and three-quarters of a mile wide, is the only extensive storage reservoir in the basin. Only about 13 per cent of the area is in forest, and the bareness of vegetation, in connection with the limited storage facilities and the extensive steep trap-rock surfaces, causes an excessive flood flow, which at times does a large amount of damage. The river is navigable to New Brunswick, 10 miles from the mouth, and is affected by tides to a point 4 miles higher. Records of gagings have been maintained since the year 1890 at the Delaware and Raritan Canal dam, 15 miles above the mouth of the river. In the report of the Geological Survey of New Jersey (Vol. III, p. 209) there appears a flow table

computed from these gagings, covering the years 1890–1893, inclusive, as follows:

TABLE I.—*Flow of the Raritan at Bound Brook, 1890–1893.*

[Drainage area, 879 square miles.]

Month.	Rain.	Flow.	Flow in second-feet.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February 17 to 28	1.58	0.98	2,772	1,406	1,938
March	6.26	6.13	17,818	872	4,727
April	2.74	2.26	3,265	874	1,773
May	4.95	1.96	4,060	752	1,489
June	3.97	1.32	2,824	426	1,040
July	5.68	1.18	2,022	498	898
August	5.18	1.58	3,405	498	1,205
September	4.13	1.34	2,823	493	1,064
October	6.74	3.06	7,133	859	2,360
November	.88	1.30	1,779	781	1,016
December	3.55	2.16	7,526	462	1,654
1891.					
January	7.06	4.92	23,746	420	3,738
February	4.21	3.47	6,056	1,295	2,931
March	4.64	4.47	10,142	1,386	3,404
April	1.83	1.62	3,439	512	1,276
May	2.70	.59	735	245	450
June	1.75	.24	509	113	189
July	3.92	.28	326	180	213
August	6.58	.94	5,804	148	716
September	1.72	.86	2,564	253	687
October	2.68	.43	804	208	328
November	2.21	.54	1,174	201	426
December	4.74	2.36	8,215	292	1,708
1892.					
January	5.58	4.57	22,760	990	3,482
February	1.19	1.31	5,182	720	1,066
March	3.98	2.59	7,941	796	1,974
April	2.02	1.25	1,893	677	985
May	4.62	1.47	3,177	513	1,120
June	4.06	1.60	10,927	443	1,261
July	4.11	.57	2,764	180	434
August	3.61	.47	2,201	180	358
September	2.75	.31	711	180	244
October	.32	.24	201	122	183
November	6.99	2.18	20,698	122	1,718
December	1.68	1.29	2,610	609	983
1893.					
January	3.39	2.11	12,514	720	1,608
February	6.23	4.16	15,772	1,228	3,494
March	3.14	5.27	19,125	878	4,016
April	4.65	4.00	10,091	918	3,152
May	4.28	3.30	10,987	387	1,515
June	3.57	.64	2,130	180	504
July	3.14	.43	820	180	328
August	8.27	1.45	5,893	180	1,105
September	3.60	.71	3,284	157	559
October	3.86	.95	4,494	180	724
November	3.59	1.50	7,352	291	1,190
December	3.12	2.63	2,698	180	2,004

As a source of water power the Raritan River is not so important as the size of the drainage area and the fall of the river would indicate. The tributaries are widely divergent, and do not, as in the most valuable power streams, join in a common course at any considerable distance above the mouth of the river. In this case the important branches of the system are not united until they arrive at a point within 7 miles from the head of tide water and even then at an elevation of only 17 feet. The largest developed power is at High Bridge,

on the South Branch. The extreme floods above mentioned occur frequently, unfitting the basin for any large development of power.

It would seem, upon first consideration, that the Raritan River is not especially valuable as a source of water supply. In quick-spilling basins large amounts of suspended matter are brought down, and in this river there is nearly always apparent a varying amount of red mud. Upon settlement, however, the water is suitable for public use, and there is no reason why excellent water supplies could not be derived from this stream by proper management; but up to the present time the river has been very little utilized for this purpose.

TRIBUTARIES OF THE RARITAN.

SOUTH RIVER.

This river rises in or near Freehold Township, at a point 20 miles due south from where it empties into the Raritan at Sayreville. The flow is much more steady than that of any other branch of the system, and this has led to an extensive use of the stream as a source of power. No large water supply can well be conserved in this drainage area. At the present time, it is true, the city of Perth Amboy derives its water from Tennent Brook, a tributary of South River, but the daily consumption amounts to practically the normal yield of the watershed. It would be possible, by carefully selecting sites for small reservoirs, to conserve several small supplies which, when combined, would be of considerable value.

NORTH BRANCH OF THE RARITAN.

The drainage area of North Branch occupies 191.6 square miles, in the northernmost portion of the Raritan Basin. It is sharply divided into the highland area and red sandstone plain, the former occupying the greater part of the country tributary to this branch. It lies at an elevation of 800 to 1,100 feet, 30 per cent of which is in forest. The population averages 72 per square mile. The red sandstone plain has an elevation of from 200 to 300 feet.

Mr. C. C. Vermeule, author of the report of the Geological Survey of New Jersey above referred to, estimates that there are 7.8 horsepower per foot of fall at the mouth of North Branch. In the entire tributary there are developed 1,052 horsepower at 46 sites.

There are many possibilities for developing excellent water supplies in the basin of the North Branch. Mr. Vermeule states that on the Lamington River, which is the main affluent of the tributary, there is an area of 31.4 square miles above the 500-foot contour which can be developed to yield 21,000,000 gallons daily. Similarly on the North Branch, above the junction of Peapack Brook, there is a drainage area of 29.1 square miles, from which may be derived 19,000,000 gallons a day. At other points in the basin there may be economically gathered a total of about 20,000,000 gallons daily.

SOUTH BRANCH OF THE RARITAN.

This branch drains 276.5 square miles of territory, which is divided into the highland area and red sandstone plain, like that on the North Branch. In this case, however, the plain occupies the larger part of the basin, with an average elevation of about 400 feet. Budd Lake, already described, lies at the head of the South Branch.

As a source of water power South Branch has been rather extensively developed. At 67 sites there is developed a total net horsepower of 2,681.

As a source of water supply the entire basin has a capacity of nearly 100,000,000 gallons daily, with 7 inches storage. Budd Lake has a watershed of 4.5 square miles, is at an elevation of 933 feet, and affords a pondage which will supply 3,000,000 gallons daily.

POLLUTION IN RARITAN RIVER.

The country included in the drainage basin of the Raritan has not yet been sufficiently developed to be damaged to any great extent by sewage, except possibly in the lower part. On the highland tributaries there are few important towns, and the character of the water is not affected to any great degree by pollution. The first city above the mouth of the Raritan is New Brunswick, which has a population of 20,006. The river at this point is tidal and within the limit of salt-water influence. Damage done by pollution can therefore be only that which arises from the general nuisance accompanying the discharge of sewage.

A few miles above New Brunswick is Bound Brook, a borough of 2,622 inhabitants, while farther on are Somerville and Raritan, towns of 4,843 and 3,244 inhabitants, respectively. These three places contribute a certain amount of pollution, which, while it does not do any appreciable damage to the general resources of the river, certainly unfits it for use as a source of water supply without filtration.

Above Raritan there are numerous small villages of a few hundred inhabitants, but all of these are unimportant as agencies of pollution.

The Raritan River, in spite of its proximity to the metropolis of the United States, strangely enough, presents a fairly clean record as to pollution except in a limited area about the mouth of the stream. It is thus notable, especially when contrasted with other rivers in this part of the country, and the contrast shows in a striking manner the difference between water resources yet unimpaired and those which have been injured or destroyed by careless and inconsiderate municipal management. In this case we find that in the majority of tributaries the water flowing out of the Raritan Basin is fit for immediate use in a public supply. The water powers developed have not been reduced in value by reason of any nuisance arising from the concentration of municipal sewage behind the various milldams. Fish-

eries have been preserved intact. The ice, as far as it is harvested, is above reproach, and the whole country is available for economic development. Let us see how it appears in the case of a river draining the country immediately adjoining.

PASSAIC RIVER.

By far the most valuable drainage system in New Jersey is that of the Passaic. It comprises a territory of 941.1 square miles, in which are situated the drainage areas of the Passaic proper (including the upper and lower valleys), the Saddle, Ramapo, and Wanaque rivers, which extend into New York State on the north, and the Pequanac, Rockaway, and Whippany on the west. Within this territory there are said to be 8 square miles of lakes and 26 square miles of swamp land.

The Passaic River rises in Morris County, in a region adjacent to that from which the North Branch of the Raritan is derived. Its course is exceedingly irregular, passing in or adjacent to six counties before finally reaching Newark Bay. The distance from source to

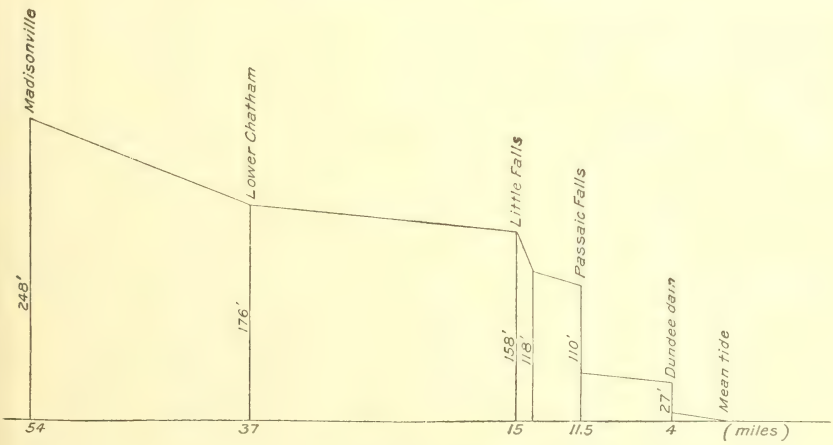


FIG. 1.—Profile of Passaic River.

mouth in a direct line is about 25 miles, while the river measures somewhat over 80 miles in its course.

The profile of the river is interesting and shows clearly the amount of power available in the lower valley. Tide influence extends about 13 miles above the mouth of the river, to a point nearly opposite Passaic. Commerce is developed extensively at Newark, and the river is navigable to the head of tide water. Four miles above this point is Dundee dam (see Pl. III, *A*), the lowest power site in the main river. Above it is a drainage area of 822.4 square miles. The fall is 22 feet, and the net horsepower developed is 1,235. The elevation of the crest of Dundee dam is 27 feet above mean tide. From this point there is a rise of 13 feet in 7.5 miles to the foot of the Great

Falls of the Passaic (see Pl. I, *B*), an imposing cataract, sheer 70 feet in height. In a distance of 4 miles, from the top of Great Falls to the foot of Little Falls, there is a rise of 8 feet. The series of falls and rapids at Little Falls, together with the height of the dam at the crest, make a total rise of 40 feet. This point is the head of power on the main river; it marks the boundary between the middle and lower valleys of the Passaic, uniting the drainage from an area of 772.9 square miles. The elevation is about 158 feet above mean tide, and the distance from tide water is only 15 miles.

At Two Bridges, a short distance above Little Falls, Pompton River enters the Passaic. Above Two Bridges the Passaic follows a winding channel 22 miles long, through a large meadow area, until at Chatham, at an altitude 6 feet above Two Bridges, the bed takes a sharper grade. From this point to the source of the stream, a distance of 18 miles, there is a rise of 72 feet.

The resources of the river that are developed most completely in the lower valley of the main stream are considered in detail in Vol. III of the report of the Geological Survey of New Jersey and in the report of the Tenth Census (Vol. XVI, pp. 647–652), so that only a general description will be given here. From mean tide up to the crest of Little Falls, 102 feet is developed and only 25 feet of the remainder is available for development. The Dundee dam is 450 feet long and impounds a lake of 224 acres, diverting the entire flow of the river in dry seasons. There is here a continuous horsepower during nine months of the year of 36.18 per foot fall, which, when used ten hours a day, allows the Dundee Water Power and Land Company to rent 1,764 horsepower. The fall of the stream has been carefully recorded at this point since 1877, and the results of the record are given in Tables II and III. These are compiled from a diagram in the report of the New Jersey geological survey above referred to.

TABLE II.—*Daily flow of Passaic River at Paterson and Dundee.*

[Inches on watershed.]

	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average.
1877	0.029	0.081	0.202	0.107	0.032	0.021	0.015	0.015	0.013	0.096	0.164	0.081	0.071
1878	.084	.138	.126	.046	.055	.054	.027	.053	.018	.019	.058	.237	.076
1879	.027	.071	.182	.143	.055	.034	.035	.051	.031	.010	.012	.075	.061
1880	.115	.092	.080	.030	.036	.012	.013	.....	.012	.011	.027	.021	.041
1881	.037	.131	.215	.042	.029	.056	.037	.010	.010	.010	.018	.052	.054
1882	.069	.171	.127	.117	.105	.061	.061	.018	.197	.043	.019	.038	.094
1883	.031	.115	.106	.098	.053	.024	.033	.013	.013	.047	.044	.024	.050
1884	.092	.215	.157	.094	.067	.022	.043	.030	.010	.019	.035	.011	.066
1885	.137	.081	.066	.115	.054	.016	.015	.026	.010	.027	.089	.102	.063
1886	.109	.189	.097	.114	.113	.034	.017	.018	.010	.018	.032	.037	.066
1887	.105	.171	.118	.087	.039	.069	.080	.052	.014	.027	.021	.109	.074
1888	.145	.138	.166	.195	.024	.014	.013	.034	.160	.015	.105	.138	.096
1889	.192	.087	.104	.137	.104	.059	.088	.145	.142	.055	.215	.148	.123
1890	.066	.118	.107	.099	.087	.051	.031	.035	.151	.084	.047	.051	.077
1891	.192	.205	.169	.076	.029	.015	.014	.023	.023	.012	.026	.065	.071
1892	.158	.052	.065	.054	.045	.038	.019	.019	.014	.011	.048	.039	.046
1893	.121	.203	.227	.130	.155	.077	.025	.023	.020	.041	.....	.056	.098
Monthly average	.101	.133	.136	.099	.064	.039	.033	.035	.050	.032	.067	.070	.....

A. ALONG THE PASSAIC BELOW PATERSON.

B. GREAT FALLS OF THE PASSAIC AT PATERSON, N. J.

TABLE III.—*Daily flow of Passaic River at Paterson and Dundee.*

[Cubic feet per second.]

	Jan.	Feb	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly average.
1877	640	1,190	4,467	2,365	706	464	330	330	286	2,123	3,924	1,790	1,570
1878	1,856	3,049	2,785	1,014	1,215	1,193	596	1,171	396	418	1,281	5,239	1,680
1879	596	1,567	4,022	3,159	1,215	750	772	1,127	684	220	262	1,658	1,347
1880	2,541	2,032	1,768	662	794	264	286	..	264	242	596	464	907
1881	816	2,895	4,753	926	640	1,237	816	220	220	220	396	1,149	1,193
1882	1,523	4,078	2,807	2,585	2,321	1,347	1,347	396	4,357	1,051	418	838	2,079
1883	684	2,541	2,343	2,164	1,171	530	728	286	286	1,039	973	530	1,105
1884	2,032	4,753	3,770	2,076	1,479	486	951	662	220	418	772	242	1,457
1885	3,027	1,790	1,457	2,541	1,193	252	330	574	220	596	1,966	2,255	1,391
1886	2,409	4,176	2,142	2,519	2,497	750	374	396	220	396	706	816	1,457
1887	2,321	4,078	2,607	1,922	860	1,516	1,768	1,149	308	596	464	2,469	1,636
1888	3,203	3,049	3,968	4,308	530	308	286	750	3,836	330	2,321	2,949	2,123
1889	4,242	1,922	2,299	3,027	2,299	1,304	1,944	3,506	3,440	1,215	4,753	3,572	2,719
1890	1,357	2,607	2,365	2,186	1,922	1,127	684	772	3,638	1,856	1,039	1,127	1,702
1891	4,242	4,533	4,034	1,680	640	330	308	508	508	264	574	1,435	1,570
1892	3,792	596	1,435	1,193	995	838	420	420	308	242	1,061	860	1,017
1893	2,673	4,489	5,019	2,873	3,726	1,702	552	508	442	907	....	1,237	2,167
Monthly average	2,233	2,939	3,005	2,186	1,413	860	728	772	1,105	706	1,479	1,548	.. ..

Concerning the methods of observation and accuracy of the determinations set down in Tables II and III, Mr. C. C. Vermeule, author of the report, says:

We have, by the courtesy of several users of water power, been able to obtain measurements of flow covering a period of seventeen years and a very wide range of rainfall conditions, from 70.88 to 37.03 annually. These gagings were at Little Falls and points below, and have been reduced, compared, and adjusted, two series being for several years contemporaneous. The results we have much confidence in. They are consistent, and bear the test of close analysis as well as any series of gagings we have made.

Table II gives the average daily flow in inches upon the watershed for each month of the period 1877–1893, and also the daily flow for each year and the monthly averages for the whole term. Table III gives similar information, except that it is expressed in terms of cubic feet per second actually flowing through the channel.

The power site at Great Falls, Paterson, is one of the oldest large water powers in the United States. Above the head of the falls is a low stone dam, affording, however, sufficient pondage to concentrate the entire dry season flow into working hours. The Society for Establishing Useful Manufactures, which controls this power, receives about $36 per gross horsepower per annum for about 2,300 horsepower, but the dry-weather flow does not supply more than half of this, and the power is not, therefore, guaranteed. The conservance of water from the upper Pequanac area for the city of Newark and the large drafts upon the river at Little Falls for the supply of Paterson, Passaic, and Jersey City have increased the uncertainty of the power at this place. The Rockaway area is now being set apart

for the use of Jersey City, and it is expected that the constantly increasing demands of the water-supply interests will soon bring the power values to a very low basis. The power, both at Dundee and Great Falls, has passed into the control of the New Jersey General Security Company, a corporation closely allied to the East Jersey Water Company, and the contest between power and water-supply interests which was at one time probable has been averted.

At Little Falls about 450 horsepower was developed, but it has been greatly reduced by the lowering of the dam for the purpose of draining the Great Piece Meadows, a wide area over which the water stands for days during freshets. The actual power value is therefore not great. Since the assumption of control by the East Jersey Water Company, the necessity for greater pondage has not been evident, sufficient being necessary to properly flood the water intake only. This intake is located on the north side of the river, a little above and at a short distance from the dam. Above the meadows the power sites on the main stream are not of great importance.

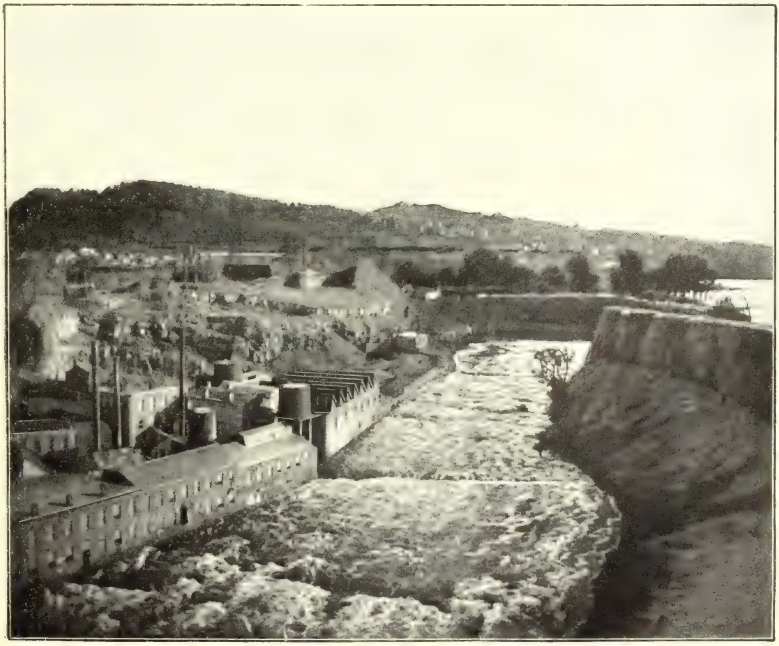
This stream forms a nucleus for a water supply which in capacity and quality can not be excelled in the metropolitan district, and from the manner in which it is now being developed it is probable that at no distant date that part of the river between Little Falls and Passaic will lose much of its value as a source of power.

TRIBUTARIES OF THE PASSAIC.

The Pompton River, which joins the Passaic at Two Bridges, above Little Falls, combines the flow of the Ramapo, Wanaque, and Pequanac, representing a combined area of 379.9 square miles. Through the Great Piece Meadows flows Rockaway River, draining 138.4 square miles, and farther up the Whippany, draining 71.1 square miles. Each of these areas forms by itself a gathering ground from all of which, except the latter, can be diverted water supplies equal to almost any emergency which the great cities of northern New Jersey are likely to encounter during the next century. The Rockaway and Pequanac, as stated above, have already been claimed. The Ramapo is now under the control of a New York corporation, which endeavored to secure a metropolitan monopoly. There remain only the Wanaque, a small available area in the Whippany, and the Upper Passaic for future development. These will be considered, each by itself as a separate stream, after we have examined the Passaic proper as a source of supply.

In spite of the largely diverted drainage of its highland tributaries, the Passaic will always be a valuable source of water supply, for it possesses a large drainage area of itself. Above Little Falls, on the main river, there is at the present time a supply that will afford, without storage, nearly 88,000,000 gallons daily. With the highland

A. GREAT FALLS OF THE PASSAIC AT PATERSON, FROM THE CREST.



B. PASSAIC RIVER BELOW GREAT FALLS AT PATERSON.

tributaries diverted, as they are likely to be in the future, there will still be a drainage area of 208 square miles, affording a supply of approximately 25,000,000 gallons daily, without storage. For years the cities of Newark and Jersey City took water from the river at Belleville, below Passaic, amounting to from 30,000,000 to 40,000,000 gallons daily. The intakes are now out of use, Newark having gone up to the Pequanac area for its water supply and Jersey City to Little Falls temporarily, until the supply from the Rockaway shall have been established. Immediately above Little Falls, on the meadows, there is no good point on the Passaic for a reservoir, and the large area of flat land causes generally muddy and unsatisfactory water. Above this, in the upper Highlands, is an excellent basin, called Great Passaic Swamp, which might easily be set apart as a storage reservoir. The drainage area is small and rather thickly populated, yet the situation remains available and can be used in case of need.

SADDLE RIVER.

This is the lowest and least important branch in the Passiac system. It rises in Rockland County, New York State, flows south for 17 miles and empties into the Passaic about 12 miles from the mouth. The drainage area contains 60.7 square miles, underlain by the red sandstone common to the main basin. It has 8 square miles of drainage area in New York State, and the population, according to the report of the Geological Survey of New Jersey in 1894, was about 122 per square mile. As a source of water power the river is not important. Out of a total fall of 90 feet there have been utilized about 60.5 feet, the power from which is divided into 47 sites along the river, representing a gross horsepower of 1,700. It is fairly good gathering ground for a limited water supply, and might be developed as an auxiliary to be used in an emergency. With a storage of 7.5 feet upon the reservoir it would yield 14,000,000 gallons daily.

RAMAPO RIVER.

Although emptying into the Passaic by way of Pompton River, this stream belongs largely to New York State, as about 70 per cent of the 160.7 square miles of drainage area is located beyond the Jersey limits. About 75 per cent of this area is forested, and the population is approximately 60 per square mile. Gagings of the flow of the river, extending through a period of two years, were made at the works of the Pompton Steel and Iron Company, and are compiled in Table IV, which is taken from the report of the Geological Survey of New Jersey (Vol. III, 1894, p. 168).

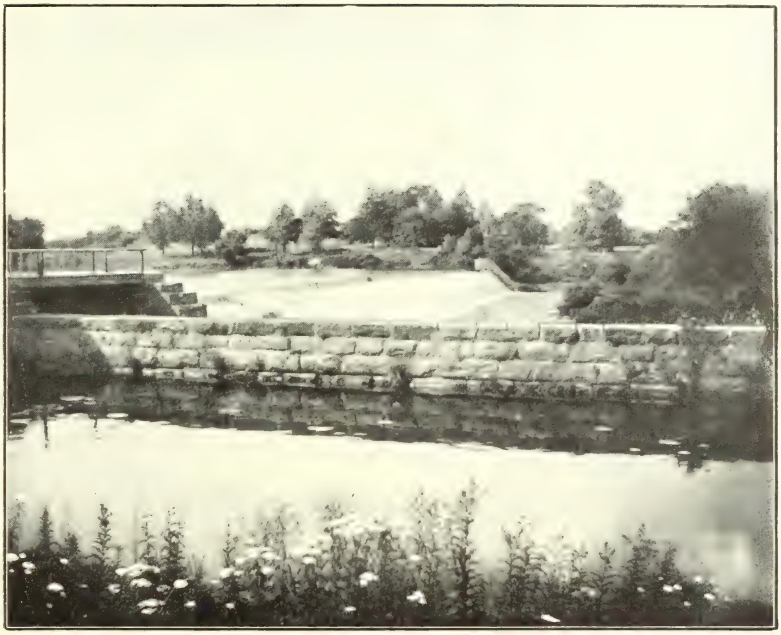
TABLE IV.—*Flow of Ramapo River at Pompton.*

[Drainage area, 159.5 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February 7 to 28	4.45	3.29	1,913	277	643
March	6.40	4.85	2,020	277	643
April	2.68	3.05	1,032	231	429
May	4.72	2.75	762	170	377
1890–91.					
June	4.98	1.25	334	55	176
July	6.06	.94	338	40	125
August	4.75	.80	601	41	108
September	4.14	1.51	948	55	209
October	6.95	2.22	839	91	301
November	.77	1.10	320	80	155
December	4.02	1.77	1,583	80	238
January	8.51	6.36	4,552	318	879
February	4.50	5.28	2,130	264	853
March	4.25	5.23	1,686	299	729
April	2.80	2.34	695	143	335
May	2.70	.67	187	41	94
June to May	54.43	29.47			
1891–92.					
June	2.13	.37	79	33	52
July	4.88	.31	70	22	44
August	5.54	.96	536	33	135
September	2.28	.67	318	40	94
October	2.39	.30	53	40	42
November	2.93	1.47	601	33	207
December	4.77	2.78	1,175	104	391
January	5.65	5.65	1,949	267	794
February	1.34	1.19	267	123	167
March	3.65	2.30	662	147	323
April	1.73	1.33	293	117	188
May	4.66	1.83	748	91	258
June to May	41.95	19.16			
1892.					
June	4.07	2.00	1,095	45	281
July	3.37				
August	4.36				
September	1.97				
October	.68	Gagings Oct. 10, 22.5 cubic feet per second.			

At Pompton, 1.5 miles above the confluence of the Ramapo with the Pompton, the Ramapo has a fall of 29 feet. The lake, which is traversed by a 7-foot dam, is about 202 acres in extent. The power developed at this place, as estimated by Mr. Vermeule, is 17.04 horsepower per foot fall. There are many other sites on the watershed which are not yet developed, but none are of great importance. The river has never been a favorite power stream.

In many ways Ramapo River is a favorable gathering ground for a city water supply. The name has, during the past few years, become well known in the metropolitan area by reason of the existence of a water corporation known as the Ramapo Company, which endeavored to acquire, and almost succeeded in obtaining, the most valuable water franchise in America—that of New York City—charging rates which, at the end of the contract period, would involve a loss to the city of New York of about $190,000,000. Although this corporation



A. DUNDEE DAM, WHICH HOLDS BACK AND CONCENTRATES THE SEWAGE FROM PATERSON.

B. DUNDEE CANAL.

controls the water rights on the New York part of the drainage area, this portion was not included as a source of supply in the plan that was presented to the city of New York. The river yields, without storage, at Pompton, 14,500,000 gallons daily. With a storage equal to 7 inches upon the watershed, the available supply would be approximately 120,000,000 gallons daily.

WANAQUE RIVER.

In its general geographic course this stream is not unlike the Ramapo. Greenwood Lake (see Pl. IV, *A*), situated on the line between New York and New Jersey, and extending into New York State about 3 miles, and Sterling Lake, entirely within New York State, afford excellent pondage. Greenwood Lake has an elevation of 621 feet, has 6 square miles of surface, and receives the drainage of 28 square miles. Its storage capacity, according to Croes and Howell, is 134,000,000 gallons, and it will supply 18,000,000 gallons daily throughout the year. Sterling Lake has an area of 321 acres and a watershed of 4.69 square miles. It will supply throughout the year about 3,000,000 gallons daily.

The only series of gagings available for Wanaque River is that made under the direction of the Geological Survey of New Jersey at the dam near Pompton station. These gagings cover a period when the stream is least affected by drafts from Greenwood Lake, and are compiled in Table V.

TABLE V.—*Flow of Wanaque River, 1890–91.*

[Drainage area, 101 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
October	6.95	2.49	594	91	217
November	.77	.93	126	44	84
December	4.02	1.59	799	44	138
1891.					
January	8.51	6.27	4,943	91	549
February	4.50	5.51	1,107	217	548
March	4.25	5.55	914	217	516
April	2.80	1.92	303	92	174
May	2.96	.61	77	45	54
December to May	27.04	21.45	Loss, 5.59 inches.		

On account of the large pondage, the flow of this river could be made comparatively uniform, and the power developed would be of considerable value. At the mouth of the river there are about 10 horsepower per foot fall, a part of which is contributed by Greenwood Lake. Power sites are available in the upper parts of the stream, and the one located in the Ringwood district could be developed to yield a steady horsepower of 2,000 during working hours.

This river forms another excellent source of city supply. It has already been stated that there is a pondage representing the drainage from 33 square miles. For the remaining run-off water there are good sites for conservance, and with a total utilization of 14 inches upon the watershed there would be afforded a supply of 75,000,000 gallons daily. Of the watershed, 28.2 square miles are in New York, and 80 per cent of the entire area is forested.

PEQUANAC RIVER.

Mr. Vermeule, author of the report of the Geological Survey of New Jersey above quoted, describes the Pequanac River as follows (p. 175):

This is another branch of the Passaic, and with the Ramapo and Wanaque forms the Pompton River just below Pompton. Its drainage area lies high on the Archean highlands. For nearly its whole course it flows transversely to the ridge and valley structure of these highlands, thus differing from the Ramapo and Wanaque, which flow through deep valleys. The headwaters of the Pequanac are at an elevation of nearly 1,500 [feet], while the mouth, at Pompton, is only 170, consequently the stream has great fall. From Post's dam at Riverdale, 2 miles above the junction of the Ramapo, to New Foundland, 12.5 miles above, the fall is 45 feet per mile; thence to Wallace's corners it is 9.2 feet per mile for 6.5 miles; for 2 miles above this, to Stockholm, it is 30 feet per mile. The watershed is 6 or 7 miles wide by 16 miles long and the branches are quite uniformly distributed along the course of the main stream, mostly coming in from the northeast. Forests cover 78 per cent of the area.

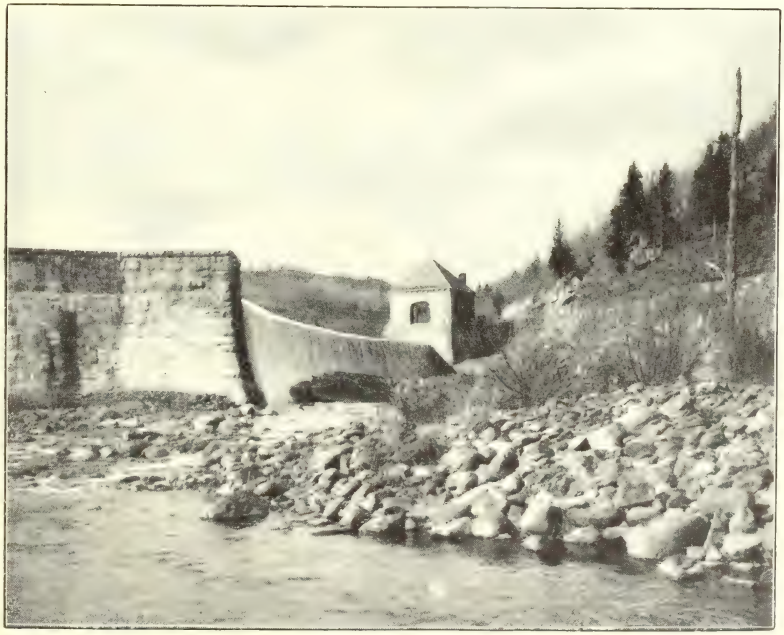
The flow of the river is compiled in Tables VI and VII, the first of which was made under the direction of the Geological Survey of New Jersey, while the second was made by Mr. Clemens Herschell, chief engineer of the East Jersey Water Company.

TABLE VI.—*Flow of Pequanac River at Riverdale.*

[Drainage area, 84.7 square miles.]

Month.	Rain.	Flow.	Flow in cubic feet per second.		
			Greatest.	Least.	Average.
1890.	*Inches.*	*Inches.*			
February	4.45	3.38	686	125	273
March	6.40	4.02	891	155	296
April	2.68	2.70	382	75	205
May 1 to 5	.31	.20	155	74	91
June					
July					
August					
September 27 to 30	.58	.08	90	25	45
October	6.95	3.61	959	25	264
November	.77	1.42	301	25	100
December	4.02	1.03	437	25	75
1891.					
January	8.51	5.17	2,352	48	387
February	4.50	5.05	1,384	46	276
March	4.25	4.12	683	46	192
April	2.80	1.50	234	46	215
May	2.70	.62	77	45	53
December to May	26.78	17.49			

A. GREENWOOD LAKE, HEAD OF WANAQUE RIVER.



B. DAM AT MACOPIN INTAKE, NEWARK WATER SUPPLY

TABLE VII.—*Flow of Pequanac River at Macopin intake.*

[Drainage area, 63.7 square miles.]

Month.	Rain.	Flow.	Average weekly flow in cubic feet per second.		
			Greatest.	Least.	Average.
1891–92.	*Inches.*	*Inches.*			
June	1.76	0.55	48	16	31
July	5.01	.27	20	20	15
August	5.75	1.39	254	16	80
September	1.93	.90	90	25	51
October	2.11	.34	23	15	19
November	3.19	1.73	172	16	97
December	4.99	3.77	415	105	212
January	5.95	5.96	450	173	335
February	.99	1.63	115	72	92
March	4.30	2.58	183	125	145
April	1.43	1.73	128	44	97
May	5.39	2.17	190	70	122
June to May	42.80	23.02			
1892–93.					
June	4.33	2.37	221	76	133
July	3.83	.53	40	15	30
August	4.63	.53	40	12	30
September	2.06	.47	53	8	26
October	.71	.16	10	8	8.8
November	6.80	1.53	224	24	86
December	1.55	1.62	140	53	92
January	4.07	1.86	212	50	104
February	6.72	3.73	293	124	212
March	3.55	6.82	614	331	383
April	4.83	4.26	277	196	240
May	5.66	4.98	606	104	280
June to May	48.74	28.86			

In past years this river has been important as a power stream, about 18 sites, with a total of 1,034 horsepower, having been developed. They have nearly all been acquired by the East Jersey Water Company and the city of Newark, and the whole drainage area will eventually be reserved for water supply. There remain notable power sites, such as those at Butler and Bloomingdale, and other points along the river, where the value of the manufacturing is still large. Such sites, however, will be preserved only so long as they do not interfere with water conservation, and therefore the future of the river as a power stream is uncertain.

As a gathering ground for water supply the value of this area has been demonstrated to the satisfaction of all concerned. The water now supplied to the city of Newark has proved excellent, and has been the means of improving the general health of the city to a remarkable extent. On account of various laxities in preparing the reservoirs and because of other circumstances the water has not been as free from sediment as is considered desirable, but sources of contamination have been largely removed, and analyses show that the character of the water is uniformly satisfactory. At the present time only the upper part of the area is reserved for a gathering ground, the water being stored in three reservoirs. That at Oak Ridge has a capacity of 2,555,000,000 gallons and is 383 acres in extent. Clinton reservoir has an area of 423 acres, a drainage area of 9.5 square miles,

and a capacity of 3,518,000,000 gallons. Canistear reservoir has a capacity of 2,500,000,000 gallons and is 350 acres in extent.

With 7 inches storage upon the entire drainage area, 14 inches may be collected annually, equal to a total daily supply of 56,000,000 gallons. In the report of the Geological Survey of the State (Vol. III, 1894, p. 179) a list of possible reservoir sites in this drainage area includes 10 locations, with a combined capacity of 23,920,000,000 gallons.

ROCKAWAY RIVER.

This stream is 40 miles long from source to mouth and has a drainage area of about 140 square miles, more than 80 per cent of which is in forest. It bears a strong resemblance to the Pequanac, although it is much less uniform in character. Within this area are numerous ponds and lakes, which afford a large proportion of storage. Splitrock Pond is 315 acres in extent, with a watershed of about 5 square miles. With the present 12-foot dam raised 3½ feet it would, according to the measurements of Mr. Vermeule, have a capacity of over 700,000,000 gallons and would, if drawn off 7 inches on the watershed, supply continuously 3,500,000 gallons daily. Green Pond, at an elevation of 1,048 feet and with an area of 460 acres, could be made to supply 1,200,000 gallons daily.

The flow of the river at Dover, as determined by the Geological Survey of New Jersey (Vol. III, 1894, p. 182), is given in Table VIII, the readings for which were made on Sundays, when the mills were shut down.

TABLE VIII.—*Flow of Rockaway River at Dover, 1890.*

[Drainage area, 52.2 square miles.]

Date.	Cubic feet per second.	Inches on watershed in 24 hours.	Date.	Cubic feet per second.	Inches on watershed in 24 hours.
March 30	253	0.180	August 24	78	0.056
April 6	182	.129	August 31	78	.056
April 13	182	.129	September 7	50	.036
April 20	115	.082	September 14	165	.117
April 27	115	.082	September 21	129	.092
May 4	175	.125	September 28	89	.063
May 11	103	.071	September 30	39	.028
May 18	182	.129	October 5	136	.097
May 25	121	.086	October 12	104	.074
June 1	128	.091	October 19	159	.113
June 8	110	.078	October 26	208	.148
June 15	115	.082	November 2	116	.083
June 22	115	.082	November 9	88	.063
June 29	41	.029	November 16	88	.063
July 6	80	.057	November 23	61	.043
July 20	39	.028	December 7	88	.063
July 27	272	.194	December 14	43	.031
August 3	318	.226	December 21	88	.063
August 17	39	.028			

As a source of power the Rockaway has in the past been one of the most valuable rivers in the State, furnishing in the year 1890, at 29 sites, 1,398 horsepower, with many available sites unimproved. The

water rights upon the area have now come into the possession of Jersey City, and the river will be used as a source of water supply, and in the future will not figure largely as a power stream.

Above Old Boonton, on the Rockaway shed, there are 122.5 square miles of highland-drainage area which have been included in the tract set apart for the water supply of Jersey City. The plan proposed by Patrick H. Flynn, contractor, and which was accepted by the city, provides that a main intake and reservoir shall be located at Old Boonton, which shall leave an area, as improved, for 50,000,000 gallons daily delivery, of 949 acres and a capacity above the effluent pipes of 1,362,000,000 gallons. Tributary to this reservoir will be the whole flow of Rockaway River, including the waters of Longwood Valley, Green Pond, Denmark Lake, Beach Glen, Splitrock Pond, Dixon Pond, Showgum Lake, and tributary streams.

Provision will be made for increasing the supply by raising the height of the dam so that the area of the reservoir will be 1,177 acres, with a capacity of 12,683,000,000 gallons, and a supply of 70,000,000 gallons daily.

WHIPPANY RIVER.

This stream is comparatively unimportant as a source of power, and the area is not well developed to become a source of water supply. The population on the watershed is large and furnishes a large measure of pollution, to which reference will be made below.

POLLUTION OF PASSAIC RIVER SYSTEM.

It needs only a superficial inspection of the Passaic River at any point below the city of Paterson to discover the bad state of affairs there existing. Commencing in a small way, the sewerage systems emptying into this part of the stream have increased with the growth of the municipalities, until the conditions all along the lower reaches of the river have become insufferable. The clutch of pollution seems to have fastened itself there, and in spite of the best efforts of intelligent men no satisfactory legislation has yet been enacted to alleviate the conditions. In considering the Lower Passaic—i. e., that part lying between Little Falls and Newark Bay—the Passaic Valley sewerage commission, created by an act of the legislature of New Jersey in February, 1896, described the conditions in its report dated February, 1897, as follows:

The great extent of the pollution of the Lower Passaic may be illustrated in several ways. It is apparent to the eye in the conditions of the river during the summer, in the foulness of the shores where sewage-laden mud, when exposed to the sun, gives out foul odors; and it is demonstrated by every practical test. The cities of Newark and Jersey City have been compelled to seek water supplies elsewhere at great expense, and the immediate decrease in zymotic diseases in those places which followed the change has shown how necessary it was.

Fish life, excepting a few hardy kinds, has disappeared from the river, and fifteen years ago shad, which formerly frequented the stream, abandoned it. The manufacturers have reported that the acid in the sewage-laden water has affected the boilers so as to make its use inadvisable. The use of the river for pleasure purposes, which at one time made it a delight to thousands, has become comparatively infrequent, and the attractiveness of the river [see Pl. I, *A*] may be said to have disappeared.

The commissioners in their meetings at the various towns on the river found all citizens deeply concerned and anxious for action to remove pollution. Their testimony was substantially identical, and while there was a natural desire to avoid doing injury to the fair name of their towns, it was their unanimous sentiment that the pollution of the river had caused great depreciation in property values along the stream. During the hot months residences within a short distance of the river were reported to be almost uninhabitable on account of the stench, and the necessity of keeping windows closed on hot nights to bar out the evil odors was frequently mentioned as showing the extent of the actual nuisance. The injury to property at all points below Paterson was testified to be large and increasing, despite the many natural advantages of the valley and its neighboring heights for suburban residences. The actual direct effect of the stench upon the public health was discussed with caution by physicians and health authorities, but that its influences were gravely injurious admitted of no doubt.

Finally, the quantity of sewage discharged, compared with the low-water flow of the river, was shown to be beyond the power of the river to assimilate, and exceeded the limits which have been regarded as permissible for an open stream by sanitary authorities of other countries and States.

The ratio of increase in population for the Lower Passaic district from 1880 to 1890 is placed by the engineers at 43.2 per cent, and from 1890 to 1895 at 22.6, the ratio for the five years thus exceeding that of the decade previous. The river now receives the sewage of the cities of Paterson, Passaic, Orange, Newark, and the towns of East Orange, Bloomfield, Montclair, Harrison, Kearney, East Newark, and part of Rutherford. Sewerage facilities for other places are an admitted necessity of the early future. It therefore appears beyond question that the river pollution is sure to increase enormously unless remedial measures be taken.

This part of the investigation by the commissioners therefore demonstrated:

That the daily discharge of 70,000,000 gallons of sewage into the Passaic River below the Great Falls of Paterson is beyond its power to assimilate.

That the pollution has become a nuisance to residents along the banks by the stench and had caused depreciation of property and injury to health.

That the fisheries had been destroyed.

That the river had ceased to be desirable for pleasure purposes, boating, bathing, etc., no longer possessing the park values which so generous a stream should afford the large population on its banks.

That the use of the river for manufacturing purposes is suffering on account of the pollution.

In short, the pollution of the Lower Passaic River appeared to the commissioners to be completely established as a public nuisance, an injury to health, and an increasing menace to property interests from the beginning at the Great Falls to below Newark.

The report of the commission, quoted above, in dealing with conditions of the Upper Passaic portion, states that the pollution upon that part of the drainage area was inconsiderable, yet the rapid growth of the municipalities thereon warranted the belief that in a short

space of time the pollution entering the river above Little Falls would be as unfavorable in its effect upon the river as that of the Lower Passaic, and recommended that there be absolute prohibition of the use of the main stream or tributaries of the Upper Passaic watershed for any crude sewage, and that the extent to which filtered effluent may be permitted to enter this stream should be subject to regulation by a commission in charge of the purification of the river, with power to prevent nuisance. The increase in population since that time has been beyond the expectations of the commission, and the laws that have since been enacted for the protection of rivers are provided with unsatisfactory means of enforcement. There is no doubt whatever that the pollution within this area is far more extensive than at the date of the above-quoted report. It is also true that the commission recognized the enormous burden imposed by the pollution in the Lower Passaic and gave more careful attention to that part of the river than they did to the highland area. Let us therefore examine the conditions as they now exist in the river system above Great Falls, Paterson.

Four miles up the river is Little Falls, a town of 2,908 inhabitants, without any public system of sewerage, but nevertheless producing considerable pollution from private drains and factories. Analyses that have been made of the water at Little Falls dam and at Great Falls dam show an appreciable increase in organic matter at the lower station, and bacteriological examinations indicate at times even more strongly the presence of sewage below Little Falls. The cities of Paterson and Passaic, which have in the past taken their water supply from the head of Great Falls, have not during that time been free from epidemics of typhoid, which, in the opinion of the sanitary officials, have been traceable to the water supply.

Farther up the river, beyond the Great Meadows, are the towns of Madison and Chatham, containing, respectively, 3,754 and 1,361 inhabitants. Neither of these has a sewerage system, although one is projected in Madison. The pollution of the river at these towns is more than would be expected from places of their size and condition. Still farther up is Summit, a city of 5,302 inhabitants, having a sewerage system that has been extended through the more thickly settled parts of the city. A sand-filtration area has been provided on the banks of the Passaic, which has been unsuccessful from the standpoint of purification, the effluent being not at all satisfactory, putrifying in a short time and causing a serious nuisance at the Chatham dam, a few miles below. Indeed, so unsatisfactory has been the work of this filter that its abandonment has been practically decided upon. A plan has received legislative authority whereby Summit may join with Milburn, Vailsburg, West Orange, South Orange, and a part of Newark in the construction of a tide-water trunk sewer which shall discharge into Arthur Kill.

Upon the Whippany are Morristown and Morris Plains, the former

with a population of 11,267, both without sewerage systems, and the former especially contributing a large amount of sewage by means of private drains from houses and factories, so that the river and its branches ramifying through the city often present a most disgusting sight. It is not apparent to the observer that the municipal authorities there have taken any effectual steps to prevent pollution of these streams, and in certain parts of the town sewage may be seen running into the brooks via the street gutters.

Boonton, Rockaway, and Dover, with a combined population of 11,322, are situated upon Rockaway River. All three are in the drainage area embraced in the reservoir now under construction, the waters of which will reach up well into the town of Boonton. In the contract entered into between the city of Jersey City and Patrick H. Flynn, the contractor, there is a provision that all sewage shall be diverted from the catchment area, and a plan has been provided whereby the contractor shall build an intercepting sewer which shall collect all the sewage from these three municipalities and empty it into the Rockaway below Old Boonton. The present plan, therefore, will not relieve the river of its pollution, except upon that part of the Rockaway above the proposed dam.

Upon the streams converging into the Pompton are Bloomingdale and Butler, with upward of 800 people, and Pompton Village, at the mouth of the Wanaque, and upon the Ramapo in New York State are Suffern, Hillburn, and Tuxedo, the former of which has a small sewerage system emptying into the river. Here is an instance of interstate pollution. Although at present not of great importance, there is every reason to believe that as the town increases in size the pollution may become sufficiently extensive to affect the value of the Ramapo watershed in New Jersey. The laws that may be enacted and the surveillance which it is hoped to establish in New Jersey over watersheds can have little effect in New York, be they enforced ever so efficiently. The same is true of the upper part of the Wanaque watershed, and also of Saddle River. Greenwood Lake, situated in both States, is a favorite summer resort, within easy distance of New York. There is likely to develop a community of no mean importance at the New York head in years to come, the pollution from which would injure not only the water-supply value of the lake, but also the ice industry, which amounts annually to about 60,000 tons.

In the year 1899 the East Jersey Water Company, being compelled to give up the water from the Pequanac, which would in September, 1900, pass into the hands of the city of Newark, offered to another municipality with which the company was under contract, and to which it was then furnishing Pequanac water, a supply from the new intake at Little Falls. The town officials not being satisfied with the proposed change, and believing the water to be inferior to that of the highland stream, employed Mr. George W. Fuller, of New York,

to examine into and report upon the subject. After a period lasting six months, during which the whole matter was explored in minute detail, Mr. Fuller submitted his report, from which the following extract is made:

While admitting that Passaic River water from Little Falls might be used * * * without any serious detriment to the public health, it is my judgment that this water can not, from a strictly sanitary standpoint, be rated as a pure and wholesome water. This judgment is based on the fact that there are no thoroughly efficient means of eliminating the germs of water-borne diseases before they shall reach the consumers at * * * in the event that such disease should become prevalent at one of nearly a dozen centers of population.

The Passaic Valley sewerage commission was succeded in 1889 by the State sewerage commission. The report of this body to the legislative session of 1900 reads concerning the Passaic River as follows:

The purification of the Passaic River has been and is the greatest problem which has demanded the attention of the commission. The magnitude of the undertaking can hardly be exaggerated. The report of the Passaic Valley sewerage commission of 1897 set forth the then existing conditions. The commissioners appointed under the act of 1898 to "consider the pollution of rivers and streams in this State" said, referring to the Passaic River: "The condition of the Passaic River has been getting worse, and during the last summer the conditions were even more intolerable than during the drought of 1895." Bad as was the condition then, that during the summer of 1899 has been far worse than ever before known. As early as June serious complaints were made of its condition, which have continued during the whole summer and into the autumn.

It is a common error to suppose that the condition is solely the result of pollution of Paterson and Passaic and the municipalities at or above the head of tide water. While these communities are large polluters of the river, others are equally guilty. During much of the time the Passaic River is little more than a tidal estuary, in which the outward flow of the tide is not of sufficient duration to empty the river of the polluted water. The incoming tide meets the sewage of Newark, Orange, Bloomfield, Montclair, Harrison, and neighboring towns, driving it up the river to meet that coming from above, so that to a great extent the same water, with constantly increasing quantities of sewage being added, is driven up and drawn down by the tide until large rainfalls occur, when there may be a flow of water from above sufficient to force the sewage out and fill the river with clean water. This temporary relief continues as long as there is water coming down sufficient to force back the tide and allow the sewage to find its way into the bay.

The commission received numerous complaints from residents along the river, it having been necessary for people a half a mile from the river to close their windows during the hottest weather to keep out the stench. The constantly increasing quantity of sewage being poured into the river, together with the decreasing amount of water coming down for the dilution of the sewage, have hastened the time when some remedial action has become imperative. It is recommended that legislative action be promptly taken to abate the foul condition of the Passaic River. To this end a bill has been drafted empowering the State sewerage commission to require such other disposition of the sewage and other polluting substance as shall meet its approval, believing that when it becomes obligatory for those fouling the river to do something else with their sewage they will join with your commission in seeking the best way. The commission has sought to unite

the different municipalities in some voluntary action, and with that end in view invited the several municipalities now discharging sewage into the river to appoint committees to meet with the State commission for the purpose of considering the subject.

In a further report to the legislature of 1901, the same commission speaks concerning the Passaic as follows:

The sewage pollution of the Passaic has, during the last year, increased in its evil effects. Heretofore the objectionable odors have been limited to the summer months; but during the last autumn the stench continued until the freezing weather locked the foulness into ice. The rainfall was below the average during the autumn, and wide spaces of sewage-befouled mud were exposed to the air, giving forth nauseating odors. The effects were felt with severity all the way from Paterson to Newark Bay, and factory hands in Paterson and in Newark, near the river, were compelled to stop work a number of times on account of nausea from the river stench. * * *

The flow of fresh water from above Great Falls is showing a steady diminution, principally owing to the diversion of the river water above for city supplies, and the amount of the discharge will unquestionably increase constantly. The effect upon the river above the tidal flow, between Paterson and Dundee dam, is disastrous, leaving insufficient water to carry down ordinary sewage discharge, much of which lodged during the summer and autumn in the bare river bed, giving forth stench and threatening disease in the heart of Paterson. The scouring by floods, which served for a periodical cleansing, is now rarely effective, and the conditions seem to grow worse. The evil condition of the whole river can scarcely be exaggerated, and what was apparent to the instructed four years ago is now evident to any person who may casually observe the river.

VALUE OF PASSAIC RIVER SYSTEM AND ITS MODIFICATION BY POLLUTION.

WATER POWER AND WATER SUPPLY.

As a source of power the Passaic system is worth about $1,500,000. According to the report of Mr. Vermeule the total available gross horsepower of the stream is 8,924. Assuming the usual efficiency of 70 per cent upon the wheel, there may be developed a net horsepower of 6,246.8, which, at the average New Jersey rental of $22.50 per horsepower, would yield an annual rental of $140,553. With a capitalization of 10 per cent we find a total valuation of $1,405,530.

The value of the river as a source of water supply is a more difficult problem to estimate and varies according to the means used to collect the water. It has already been stated that at the head of Little Falls the river will supply without storage about 85,000,000 gallons daily. The only important addition to the flow below this point is Saddle River, which furnishes daily a minimum of about 2,600,000 more throughout all seasons. This total of about 87,600,000 gallons is undoubtedly a conservative estimate of the supply available at the Belleville pumping station, and the total flow of the river past that point would, except in extraordinary cases, be far greater. If, then, pollution were excluded from the Passaic and the minimum flow were

pumped from the river at Belleville, there would be no disturbance of the power value of the river, so that, in addition to the power valuation, there would be the value of the water. Pumped from the river at Belleville and raised to a height sufficient to serve the metropolitan areas of Essex and Hudson counties, this water, at a fair valuation, would bring $25 per million gallons, assuming, of course, that the present pollution had never existed.

If, however, storage is provided in the highland areas and the water is allowed to flow into the cities by gravity we shall have a measure of resource far greater than that above estimated. Mr. Vermeule states that 666,094 gallons per square mile are daily collectible with storage upon the Passaic system. Considering only the 773 square miles above Little Falls, and the 60.7 square miles of Saddle River there can be developed through storage a resource equal to 555,000,000 gallons daily. This amount of water, utilized at the extremely low rate of $15 per million gallons and on the basis of only 60 per cent conservance, would yield an annual income of $1,823,175, which capitalized at 10 per cent equals $18,231,750. Under such a system the water power would be largely if not completely destroyed, so that this value would necessarily be deducted from the above figures.

It has already been shown that the water pumped from the river below Belleville is polluted beyond all possibility of use in its crude state, and indeed the city of Newark had this fact brought to its attention during the winter of 1899, when, during a continued cold season, the consumption of water reached the limit prescribed in the contract and the water was again pumped into the mains at Belleville. The typhoid epidemic resulting therefrom was a severe lesson.

Expert examination has shown that it is unsafe to use the water from Little Falls in its crude state. If we examine the history of the water supply upon the Passaic we shall find the following facts: Previous to the year 1888 the municipalities of Newark, Harrison, Arlington, Belleville, Nutley, Kearney, Passaic, and Paterson, situated upon the Lower Passaic, and Jersey City, situated upon the Hudson, all derived their water supply from the Passaic. On the one side of the river Jersey City, Harrison, and Kearney received their supply from the intake owned by the first-mentioned city, while across the river, at Belleville, was situated the Newark pumping station. From the latter intake there were pumped 16 to 20 million gallons daily, at a cost of $15 to $17 per million gallons, while at the former intake about the same amount was taken, at approximately the same cost. Passaic and Paterson were supplied from an intake situated at the head of Great Falls and owned by the Passaic Water Company. All of these municipalities, especially those supplied from the Newark and Jersey City intakes, suffered excessively from typhoid fever, due to sewage pollution in the river.

In 1889 the source of supply of the Newark system was transferred to the Pequanac area under a contract with the East Jersey Water Company, and in September, 1900, the ownership passed to the city at the cost of $6,000,000. Although the change from Belleville to Pequanac involved a change from a pumping to a gravity system, which in years to come will be more economical, during a long term of years the fixed charges upon the plant will make the water cost Newark $30 per million gallons, an amount equal to twice the cost of the Belleville water.

The source of supply for Jersey City was, in the year 1898, transferred to the new intake of the East Jersey Water Company at Little Falls, a temporary arrangement which will continue during the completion of the dam at Old Boonton, on the Rockaway, which, when developed to a capacity of 70,000,000 gallons daily, will cost the city about $9,000,000. Here, again, the transference from pumping to gravity will, in the end, be the means of securing the water at a cheaper rate, but the fixed charges in the meantime will operate similarly to those in Newark.

In 1899 the source of supply of Paterson, Passaic, and Nutley, which had for years been taken at the head of Great Falls, was transferred to the new intake at Little Falls. The reasons for this change are not entirely confined to those of pollution, although there is no doubt, and indeed it is admitted by the officials of that company, that pollution from the town of Little Falls had rendered the water unsafe for domestic use. The cost of this change is, of course, not made public, yet it can be easily understood that so radical a move must have been attended by a considerable outlay, as well as the surrendering of large values by the disuse of the Great Falls pumping plant.

The opinion of Mr. Fuller, already stated, having been unfavorable to the Little Falls water in its raw state, and pressure having been brought to bear upon the company by the municipalities using it, it became necessary to construct a filter, which is nearing completion and which will cost about $400,000. Subsequent additional charges for maintenance will amount to about $6 per million gallons.

ICE INDUSTRY.

Up to the present time the value of the Passaic system as a source of ice supply has not been greatly injured by pollution. Greenwood Lake, which is by far the most valuable of the Passaic ice fields, affords an annual average supply of about 60,000 tons. On the river below Paterson there was in former times a fairly large ice industry, amounting in favorable seasons to 10,000 tons. It has, however, been completely destroyed by the pollution of the river, and the first of a proposed series of suits against the city of Paterson has been won in the lower court by an injured ice dealer.

FISH.

There was a time when Passaic shad were as highly valued in the eastern markets as are those in the North River to-day. The industry flourished and was a source of no inconsiderable income to the dwellers along the river. Under the present conditions only one hardy, inedible fish will live in these waters.

REALTY VALUES.

Pollution of the Passaic has caused its greatest damage in the reduction of realty values. We can not estimate with any degree of correctness the amount of this damage, but we know that it is enormous. The banks of the Passaic from Paterson to Newark are naturally attractive, and there is, in the northern portion of New Jersey, no more suitable nucleus for a public park. Especially along the shores of Dundee Lake are there situations which are ideal for suburban homes, and their accessibility to the large cities of the metropolitan area would naturally make them desirable in the eyes of that constantly increasing number of city business men who are making for themselves homes outside of Greater New York. Yet the area is practically uninhabitable—the residents along the shores are principally those who have lived there from birth and inherited the property upon which they dwell, or who moved there before the present conditions existed, and are encumbered with property which they can neither abandon nor sell. Only a few years ago the value of this land for farming purposes was from $500 to $800 per acre, and building sites were held at a much higher value. For one piece of property of 14 acres, in a particularly favored situation, $40,000 was refused less than twenty years ago. To-day, however, this plot can not be sold at any price, nor is there any market for the property along the entire shore of the lake.

SUMMARY.

We have seen that the natural resources of the Passaic system are very extensive, embracing water power, water supply, ice fields, fisheries, transportation, and natural scenic advantages, but that all but one of these have been so damaged by pollution as to produce the following results:

1. Abandonment of three water-supply intakes and the establishment of three others, at a total expense of not less than $20,000,000.
2. Extensive decline of power values because of inadaptability of water for use in boilers and in manufacturing processes.
3. Loss of annual harvest of ice weighing 10,000 tons.
4. Absolute destruction of fisheries in lower valley.
5. Impairment of realty values, the extent of which can not be too highly estimated in view of the fact that similar properties in clean localities have been made of immense value.

HUDSON RIVER.

Perhaps the most resourceful and certainly the most famous river on the Atlantic coastal plain is the Hudson. The history of its discovery and development has been many times retold; its physical characteristics are subjects of study in common schools, and its resources, especially from the standpoint of water power, have been repeatedly described, notably by Prof. Dwight Porter, in Volume XVI of the Tenth Census report, and later by Mr. George W. Rafter, C. E., in Nos. 24 and 25 of the series to which this paper belongs. It therefore seems unnecessary to consider this branch of the subject in the following pages, and as, up to the present time, very little, if any, detriment has arisen to water-power values through sewage pollution anywhere in the basin, the subject of power is not pertinent.

The extreme flatness of the bed of the Hudson throughout the first 150 miles from its mouth, and the depth of water maintained thereon, give to it the character of an elongated bay, or arm of the ocean, rather than that of a river. At Troy, the head of natural navigation and also of tide water, the level of the river at mean low tide is only 2.07 feet above mean sea level in New York harbor. Under these conditions, the influence of salt water extends a great distance inland, the brackish taste being appreciable at times at Poughkeepsie, 80 miles above Sandy Hook (see Pl. V, *A*). The influx of sea water by the flood tide was studied by Mr. H. L. Mandarin, under the authority of the United States Coast and Geodetic Survey, in 1871, the results of which may be seen in Table IX.

TABLE IX.—*Specific gravities of water in the Hudson River at and below the surface, reduced to a temperature of 60° F., September, 1871.*

Distance from Sandy Hook.	Station.	End of flow current.			End of ebb current.		
		Surface, specific gravity.	Below.		Surface, specific gravity.	Below.	
			Depth.	Specific gravity.		Depth.	Specific gravity.
Nautical miles.			*Feet.*			*Feet.*	
17½	Twentieth street	1.0198	57	1.0206	[a] 1.0141	53	1.0181
34½	Dobbs Ferry	1.0024	30	1.0114	1.0013	30	1.0022
38½	Tarrytown	1.0021	30	1.0089	1.0016	30	1.0076
42½	Tellers Point	1.0011	30	1.0087	1.0013	30	1.0087
49½	Verplanks Point	1.0012	30	1.0034	1.0014	30	1.0014
53½	Iona Island	1.0017	30	1.0037	1.0012	30	1.0012
56½	Dermings Landing	1.0016	.....	1.0028	1.0012	.....	1.0021
61	Cold Spring	1.0015	30	1.0026	1.0010	.....	.....
65	New Windsor	.....	.....	.....	1.0006	.....	.....
70½	Carthage	1.0003	48	1.0016	1.0006	48	1.0012
75	Barnegat	1.0006	60	1.0006	1.0006	60	1.0006
79½	Poughkeepsie	1.0007	48	1.0007	1.0006	48	1.0005

[a] 1872.

The drainage area of the Hudson is estimated by Professor Porter as 13,366 square miles, 8,034 of this being above Troy. Its tributaries extend into New Jersey, Massachusetts, and Vermont, and the minimum flow past Poughkeepsie is said to be about 1,500,000,000 gallons daily. In his report to the Merchants' Association of New York upon

A. POUGHKEEPSIE, N. Y., THE HEAD OF SALT-WATER INFLUENCE ON THE HUDSON.

From photograph in possession of American Museum of Natural History, New York City.

B. DELAWARE AND HUDSON CANAL TERMINUS, RONDOUT, N. Y.

From photograph in possession of American Museum of Natural History, New York City.

available sources of water supply for that city Mr. James H. Fuertes computed a probable flow of 2,900,000,000 gallons daily at the time of the measurements in the table above.

Before considering the subject of pollution in the Hudson it will be advisable to examine briefly into the character of the river and to contrast the conditions which prevail with those dealt with in connection with the Passaic. We have seen that the Passaic River is a comparatively small stream, and that it has upon its banks numerous large cities and towns which pour into it a volume of sewage at times greater than the flow of the river. In the Hudson Basin we have an area more than thirteen times the size of the Passaic, contributing to a flow which exceeds the latter in like proportion. Consequently the amount of sewage poured into the river must be as great in proportion to the flow as that in the Passaic and of similar character and distribution in order to accomplish the serious results that we have noted in the latter. From the cities in the basin of the Hudson River and its tributaries there comes a pollution far greater in amount than from those in the Passaic Basin, yet the proportion of contaminating matter to the total flow is so much less in the Hudson than in the Passaic that they bear no significant relation to one another. Few if any points in the Hudson watershed have been damaged to a degree which at all compares with the distress that has arisen along the Passaic Valley, because of the fact that the natural flow of the Hudson so largely dilutes the sewage poured into it that not infrequently the effects thereof are not traceable by sanitary analysis. In the year 1893 Dr. Thomas M. Drown, now president of Lehigh University, found that the water from the river above Poughkeepsie, which is below practically all of the polluting points in the basin, did not reveal upon analysis any serious traces of sewage matter; indeed, the water appeared altogether better than that of the Schuylkill River, from which the city of Philadelphia has for years been drawing the greater part of its supply.

TABLE X.—*Average analyses of Hudson River water at Poughkeepsie, June, 1893.*[a]

[Parts per 100,000.]

	Albumenoid ammonia.	Free ammonia.	Nitrogen as nitrates.	Nitrogen as nitrites.	Oxygen consumed.	Chlorine.
At intake of Poughkeepsie waterworks, average of 9 samples taken, 5-8 feet below surface	0.0144	0.0031	0.0007	0.0108	0.5197	0.110
At one-third distance from east shore, average of 19 samples taken at surface, 30 feet and 50 feet below surface	.0137	.0034	.0006	.0106	.5159	.107
At two-thirds distance from the east shore, average of 19 samples taken at surface, 30 feet and 50 feet below surface	.0149	.0034	.0006	.0110	.5389	.109
[illegible] miles above Poughkeepsie, average of 6 samples across river, 30 feet below surface	.0143	.0034	.0006	.0085	.4606	.113

[a] From report of James H. Fuertes to Merchants' Association of New York.

In considering pollution upon the Hudson it will be necessary to take into account only that part lying above Poughkeepsie, for salt-water influence extends up to this point, and this of itself destroys many resources which have been noted in the preceding pages as subject to damage by pollution. All succeeding calculations will be based upon the watershed above this point unless otherwise noted. Above Poughkeepsie the river still maintains the character of an inland-traffic course, plied by steamers and canal boats. Pollution is therefore unavoidable, for if all city sewage were excluded from the river the ejecta from passenger steamers passing up and down would make the raw water unsafe as a domestic supply, especially when such matter was discharged near a supply intake. It appears, then, from what has gone before, that from the standpoint of pollution the Hudson divides into three sections: First, that within the salt-water influence, i. e., from New York to Poughkeepsie; second, that between Poughkeepsie and Troy, which by reason of its commercial value must be polluted; third, the upper or highland section, along which power sites are available and which partakes of the character of an ordinary power stream. In order to show the extent and population of the country drained by the Hudson the following table has been prepared, in which the populations have been calculated according to the Twelfth Census Reports:

TABLE XI.—*Drainage areas and population in the Hudson River Basin.*

State.	County.	Number of municipalities.	Combined area in square miles.	Population.	Population per square mile.	Sewered population.
New York	Essex	7	649	11,382	17.5	.....
	Warren	11	940	29,943	31.8	12,613
	Washington	11	557	31,110	55.9	3,521
	Saratoga	20	800	61,089	76.4	24,173
	Hamilton	8	1,767	4,947	2.8	.....
	Herkimer	21	1,459	51,049	35	21,074
	Oneida	21	[a] 896.7	117,518	131	71,726
	Lewis	1	[a] 72	917	12.7	.....
	Madison	1	[a] 39.3	2,024	51.5	.....
	Otsego	1	[a] 40	1,802	45	.....
	Fulton	12	567	42,842	75.4	28,479
	Montgomery	11	396	47,488	119.9	20,929
	Schoharie	16	647	26,854	41.5	2,327
	Schenectady	6	200	46,852	234.3	31,682
	Albany	13	499	165,571	331.9	132,382
	Rensselaer	17	643	121,697	189.3	86,383
	Columbia	19	691	43,211	62.5	9,528
	Dutchess	19	772	77,337	100.2	24,029
	Greene	14	660	31,478	47.7	8,219
	Ulster	21	1,157	88,422	76.4	24,535
	Orange	19	683	59,410	86.9	19,495
	Sullivan	3	[a] 60.7	8,121	13.4	.....
	Delaware	1	[a] 45	2,134	47.4	.....
Massachusetts	Berkshire	8	[a] 239	43,191	180.7	.....
Vermont	Bennington	13	[a] 520	19,407	37.3	.....
New Jersey	Sussex	10	[a] 292	13,031	44.6	.....

[a] These areas are estimated and are only approximately correct.

North of Poughkeepsie, on the east side, there flow into the Hudson, in the order mentioned, Crum Elbow Creek, Fallsburg and Landsman kills, Stony Creek, Roeliff Jansen Kill, Claverack and Kinderhook

creeks, Moordener, Wynant and Poeston kills, Hoosic River, Batten Kill, Moses Kill, and Schroon River. Of these, Crum Elbow Creek, Fallsburg Kill, Stony and Claverack creeks, Roeliff Jansen and Moses kills, and Schroon River are not important from the standpoint of pollution, as they flow into the Hudson in a comparatively pure state. Landsman and Wynant kills and Kinderhook Creek receive a certain amount of pollution indirectly at the centers of population in the courses of the three streams. Hoosic River is badly polluted, and Batten Kill to a less extent.

On the west side of the Hudson the river branches enter in the following order: Rondout Creek, Esopus, Catskill, Hannacrois, and Coeyman creeks, Norman Kill, Mohawk River, Anthony Kill, Fish Creek, Snook Kill, and Sacandaga, Indian, Cedar, and Rock rivers. Of these, Hannacrois and Coeyman creeks, Norman and Snook kills, and Sacandaga, Indian, Cedar, and Rock rivers need no discussion because of their comparative freedom from pollution. Rondout, Kaaterskill, and Catskill creeks receive considerable indirect and private drain pollution, while Wallkill and Mohawk rivers and Esopus and Fish creeks are directly polluted by sewage systems.

It has already been stated that pollution along the middle or navigable section of the Hudson above salt-water influence is unavoidable, even if city sewage were entirely excluded from the river. In order to make the whole pure it would be necessary to close the river to commerce, and as its value as a means of transportation far overtops all other values which it may have, such a suggestion is manifestly absurd. We are forced, then, to conclude that, for the present at least, while pollution may unfit the Hudson up to Troy for use as a domestic water supply without filtration, the damage to the resources is insignifiant compared to the damage which would occur by excluding sewage from the river. While the water remains fit for filtration, then, the Middle Hudson is of more value as a polluted stream than it would be if preserved unpolluted. But if the time should ever come when the condition of the Hudson should approach that of the Lower Passaic, then it would be highly necessary to enforce sewage purification upon the towns and cities along the banks. Such a contingency is, however, very remote.

The reports of the Tenth, Eleventh, and Twelfth Census bureaus show that the growth in population along the Hudson below the mouth of the Mohawk has not been marked. During the last decade the cities of Albany, Troy, and Hudson have actually decreased in population, while the gain in others has been subnormal. Any alarming increase in the amount of sewage poured into the Hudson can not, therefore, be expected, and it will not probably be in danger of becoming the consummate pest that the Passaic has become should there be no regulation of sewage disposal for generations.

It will be necessary to consider the sources of pollution along the

middle section of the Hudson in order that the conditions there existing may be clearly shown. Catskill, Hudson, Albany, Rensselaer, Watervliet, and Troy (including Lansingburg) are sewered cities along the middle section of the river, containing a combined population of 204,196. The amount of sewage discharged from these places is unknown; no gagings have been made, and any estimate which might be given would not be even approximately correct. Judging from the population involved it might be expressed as about one-half that discharged into the lower section of the Passaic.

Catskill is a village of 5,484 inhabitants, having shown a growth of 11.5 per cent during the last decade. The manufacture of bricks forms a large industry, and the textile mills are important. Its source of water supply is the Hudson, the water from which is filtered previous to distribution. A system of sewerage has been extended throughout the corporate limits, and the sewage is discharged, unpurified, into the mouth of Catskill Creek.

Hudson is a city in Columbia County, which is largely devoted to manufactures of iron and lumber. It is also the seat of several State homes and schools. During the past decade the population has dropped from 9,970 to 9,528. It is supplied with filtered water from the Hudson, and discharges about 1,200,000 gallons of unpurified sewage daily through a combined system of sewerage.

Albany, the capital of the State of New York, has also decreased in population. During the decade 1890–1900 the loss amounted to .81 per cent. Although in the past the city has suffered severely from polluted water supply, the filters recently installed under the direction of Mr. Allen Hazen, M. Am. Soc. C. E., have made Hudson River water acceptable. The sewers discharge raw wastes into the Hudson, but there appear to be no available records of gagings of the amount. The average daily consumption of water at the present time is, however, about 18,000,000 gallons.

Rensselaer, situated opposite Albany, in Rensselaer County, is a municipality in which there has been a slight growth, the population, according to the Twelfth Census, being 7,466. It is supplied with water from the Hudson, filtered by a Jewell mechanical filter. A separate system of sewerage discharges raw wastes into the river, the amount of which is said to average about 1,500,000 gallons daily. The accuracy of this statement is uncertain, however, and it is probable that the actual discharge is considerably more than the above.

Watervliet, formerly known as West Troy, and Troy, which now includes the former city of Lansingburg, have a combined population of 87,567. The increase in population at Watervliet and Lansingburg has been normal, but at Troy the Twelfth Census returns show a decrease in the last decade of 300. Troy water is largely taken from the Hudson and has caused a great amount of disease. Plans are now being executed which will relieve this condition by the conservance of a highland supply a short distance away from the city.

At Lansingburg the drainage into the Hudson has been defective, and plans for making more perfect, more direct pollution have been approved by the State board of health.

Besides the above-mentioned municipalities there are located upon the banks of this section of the Hudson the following small places included in Table XII, some of which have no public sewerage systems, yet which furnish considerable pollution.

TABLE XII.—*Population, water supply, and sewerage of certain towns on Hudson River.*

Place.	Population.			Water supply.	Sewerage.
	1890.	1900.	Change.		
Saugerties	4,237	3,679	− 540	Yes	No.
Athens	2,024	2,171	+ 147	No	Do.
New Baltimore	2,455	2,283	− 172	Yes	Do.
Coeyman	3,669	3,925	+ 283	do	Do.
Hyde Park	2,821	2,806	− 15	No	Do.
Bath	3,261	4,994	+1,733	Yes	Do.
Rhinebeck	1,649	1,494	− 155	do	Do.
Tivoli	1,350	1,153	− 197		
Castleton	1,127	1,214	+ 87		
Coxsackie	1,611	2,735	+1,124	Yes	Yes.

Above Troy navigation on the Hudson is confined to the transfer of canal boats through the pool of the State dam at Troy up the river to Waterford, where they enter the Champlain Canal. According to recent reports there has been a reduction in canal traffic in New York State, so that the value of the river above Troy for heavy traffic can be regarded as somewhat transitory. Above this point, then, the river is valuable principally for power, water supply, and ice.

Civic pollution becomes more important above the confluence of the Mohawk, where the flow is considerably less, and the danger is that, as the cities increase in population, there will arise conditions similar to those on the Passaic. The cities and villages above Troy have all shown a healthy growth during the past decade, and, strangely enough, have collectively increased at a rate far higher than places nearer the metropolis.

TABLE XIII.—*Centers of pollution on Upper Hudson.*

City.	Population.		Sewerage.	Place of disposal.	Water supply.
	1890.	1900.			
Cohoes	22,519	23,910	Yes	Hudson and Mohawk.	Yes.
Waterford	(a)	3,146		Mohawk and Hudson.	Hudson River.
Mechanicville	2,679	4,695	Combined	Hudson	Plum Brook.
Schuylerville	1,387	1,601	No		No.
Fort Edward	(a)	3,251	Yes	Hudson	Yes.
Sandy Hill	2,895	4,473	No		Do.
Glens Falls	9,509	12,613	Yes	Hudson	Do.

[a] Incorporated since 1890.

The above-named cities and villages represent a sewered population of 47,615. Mechanicville is a village devoted to manufacturing, the thread industry being the most important. It shows a growth of about 74 per cent during the past decade. Schuylerville has considerable private drain pollution, yet it is without marked effect upon the river. At Fort Edward there is a satisfactory water supply, and a sewerage system has been recently constructed which extends nearly throughout the corporate limits.

Sandy Hill is another thriving village, showing a growth of 55 per cent during the last decade. Although no sewerage system has yet been constructed, the river pollution is comparatively serious. In 1896 plans for a system of sewerage and disposal works were submitted to the State board of health and accepted, so that even though nothing further has been accomplished the establishment of another source of pollution can not be far removed. Glens Falls, a short distance above Fort Edward, is supplied with water and sewerage systems, which are well extended through the village. The place of the final disposal of the sewage is described by the village engineer, George P. Slack, as a "sink hole in ledge," which probably means that it takes the most obvious course, i. e., the Hudson River, accompanied, very likely, by a slight purification. This village has a population of 12,613, having increased from 9,509 during the last decade.

This part of the river, comprising in its drainage area about 5,000 square miles, is said to have an average flow of about 174,528,000 cubic feet daily, which is probably approximately correct. It partakes of the nature of a highland river, having a fall from Glens Falls to Troy, a distance of 46.5 miles, of 282 feet, and is largely given up to lumber business and lime manufacture.

Waterford and Cohoes are at the mouth of the Mohawk. At both places mill manufacturing is the largest industry, Cohoes possessing one of the largest cotton mills in the world. Pollution from these two cities, added to that already imparted to the Mohawk from cities above, is responsible for the high morbidity rate from waterborne diseases in the cities of Troy and Albany.

EASTERN TRIBUTARIES OF THE HUDSON.

The tributaries of the Hudson that receive only pollution incident to the drainage of unoccupied land require only slight consideration in these pages, while those that are comparatively normal as to condition of water do not come within the scope of this discussion. The tributaries entering the Hudson from the east belonging to the first class above noted are Landsman and Wynant kills and Kinderhook Creek.

Landsman Kill, a small stream entering the Hudson at Vanderburg Cove, carries considerable pollution from the village of Rhinebeck, which contains 1,484 inhabitants. A report from the secretary of the

local board of health stated that a water supply has been provided and that the village has no system of sewerage. It is further stated that at least 75,000 gallons of sewage a day enters the stream. The method of estimating this amount is not shown, however, and it is more than probable that the result is a wide approximation made with questionable data. However this may be, it is certain that the amount ejected has no appreciable effect upon the lower reaches of the river, and its presence is apparent locally only in the area immediately around the various points of discharge. The village of Rhinebeck has decreased considerably in population during the past decade, and the question of future pollution at this point can not be regarded as serious.

Wynant Kill empties into the Hudson a short distance below Troy, having flowed northwest through an agricultural region. Its ultimate source of supply is a chain of lakes in and around the town of Sandlake, in Rensselaer County. At Averill Park and other small settlements there is unimportant pollution. The drainage area seems to be slowly losing its population and the future is therefore not regarded with apprehension.

Kinderhook Creek passes through country similar to that drained by Wynant Kill. Upon its banks are the comparatively important settlements of Nassau, Valatie, and Stockport. The latter is upon Claverack Creek near its confluence with Kinderhook. The observations above made may well apply to the conditions upon this creek.

Hoosic River and Batten Kill are polluted to a greater extent than the rivers considered immediately above. Both of these streams, and especially the former, are damaged considerably by contaminating waters.

Upon Hoosic River are the centers of population shown in Table XIV.

TABLE XIV.—*Centers of population on Hoosic River.*

Name.	Population.		Water.	Sewerage.
	1890.	1900.		
Schaghticoke	1,258	1,061	No	No; many private drains in Hoosic.
Johnsonville[a]			do	No.
Valley Falls[a]			do	Do.
Hoosic Falls	7,014	5,671	Yes	Yes; separate system.
Cambridge	1,598	1,578	do	No; many private drains in Owl Kill.
Bennington	3,971	5,656	do	Yes.
North Adams	16,047	24,200	do	Yes; partly emptying into Hoosic.

[a] Part of Pittston town; no separate returns.

The Hoosic drainage basin extends through Rensselaer and parts of Washington and Columbia counties into the States of Vermont and Massachusetts, comprising an area of 730 square miles. The average flow of the river is stated to be about 450 cubic feet per second, with a minimum of 180. It is a most important power system, and for that reason there is a fairly large population within the basin.

At Schaghticoke, a village of 1,061 inhabitants, there is no public water supply and no sewerage system, but there is nevertheless a large amount of pollution from drains and factories, which undoubtedly has an appreciable effect upon the water of the river.

At Hoosic Falls there are 5,671 inhabitants supplied with water from wells dug along the banks of the river. Filtration is such that the pollution above this point does not affect the water drawn from the wells. There is also a separate sewerage system, emptying raw sewage into the Hoosic.

On a branch of the Hoosic called Owl Kill is the village of Cambridge, with 1,578 inhabitants. It has a water supply and no sewers, so that the pollution, although considerable in amount, is somewhat indirect.

Bennington, in Vermont, with a population of 5,656, has a sewerage system emptying into the Wallomsic, a branch of the Hoosic.

At North Adams, Mass., a city of 24,200 inhabitants, lying near the head of Hoosic River, there arises the most serious contamination along the whole length of the stream. The condition is at times exceedingly offensive, and the local board of health has found it advisable to prohibit the sale of ice from the river and from polluted ponds emptying into it. The condition is well set forth in the reports of the Massachusetts State board of health. The following table of average analyses is taken from the report issued for the year 1900 (p. 330), the water having been taken from the river at Williamstown, a short distance below North Adams.

TABLE XV.—*Chemical examination of water from the Hoosic River at Williamstown, Mass.*

[Averages by years, in parts per million.]

Date of collection.	Turbidity.[a]	Color.[b]	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1888	D.	1.0	0.187	0.040	0.010	0.306	2.4	102.1	.....
1894	D.	2.3	.265	.111	.009	.157	3.5	107.7	73
1895	D.	2.8	.334	.146	.013	.162	3.9	124.1	81
1896	D.	2.1	.326	.261	.015	.323	4.4	118.3	81
1897	D.	2.3	.273	.125	.008	.252	2.7	99.2	64
1898	D.	2.4	.286	.152	.005	.187	2.6	91.3	58
1899	D.	2.8	.505	.223	.018	.141	5.0	123.7	69
1900	D.	2.4	.436	.328	.026	.146	4.7	118.5	65

[a] "D." is a term used to indicate the general appearance of the water, and means "decided."
[b] Determined according to Nessler standards.

In the above table it is of interest to note the increase from year to year in the ammonias, nitrites, and chlorine, indicating unmistakably the increase in pollution from North Adams, along with municipal growth.

The Hoosic River is therefore a stream which becomes a troublesome nuisance almost at its starting point, and passes through Vermont into New York State in a badly damaged condition. During

the long stretches through New York it improves in quality through oxidation of its organic contents and sedimentation of its suspended matter, and, in spite of the contamination it receives at various points, enters the Hudson probably in better condition than when it crosses the New York-Vermont State line. It is the clearest case of interstate pollution which we have yet considered.

Next above the Hoosic is Batten Kill, which is one of the most valuable power streams tributary to the Hudson. It has a drainage area of about 450 square miles, and the average flow has been roughly determined at about 280 cubic feet per second.

The important centers of population along the river are Greenwich and Salem, which have 1,869 and 3,191 inhabitants, respectively. Neither of these places has a public sewerage system, yet pollution of the river from these points is well marked.

It is a surprising fact that nearly all of the towns and villages lying east of the Hudson in New York seem to be unprogressive, many of them having decreased in population during the last decade. Pollution is therefore not a growing danger in the eastern tributaries, and the water which flows from them into the Hudson is pure as compared with that of the main river.

WESTERN TRIBUTARIES OF THE HUDSON.

Pollution upon the western basin of the Hudson is far more serious than that on the east. The facts concerning the important rivers joining the main river from the west are given in Table XVI

TABLE XVI.—*Western tributaries of Hudson River.*

Stream or branch.	Number of pollution points.	Number of sewerage systems.
Rondout Creek	3	None.
Wallkill	16	3; two doing considerable damage.
Esopus Creek	8	1; part of Kingston system.
Catskill Creek	4	None.
Kaaterskill	6	Do.
Hannacrois Creek	None.	Do.
Norman Kill	2	Do.
Mohawk River. (*See* special discussion below.)		
Anthony Kill	1	1
Fish Creek	2	2
Sacandaga River	3	None.
Indian River	None.	Do.
Cedar River	None.	Do.
Rock River	None.	Do.

Catskill and Esopus creeks, Wallkill River, and Rondout Creek have during the last few months received the attention of the engineering corps of the water department of New York City in cooperation with the Division of Hydrography of the United States Geological Survey. The various drainage areas have been examined, and gaging stations have been established in the streams at convenient and important points.

RONDOUT CREEK AND WALLKILL RIVER.

Entering the Hudson at Kingston is Rondout Creek, which drains an important area in New York and a few square miles in New Jersey. Its principal tributary is the Wallkill, whose drainage area is described in Water-Supply and Irrigation Paper No. 65, pages 71 and 72. At New Paltz, N. Y., a gaging station has been established, and the current-meter measurements that have been made at that place since July, 1901, are reproduced upon pages 72 and 73 of the above-mentioned report.

The principal branch of the Wallkill is Shawangunk Creek. A large amount of sewage enters the main river, and of late it has increased markedly. The principal foci of pollution are at New Paltz, Modena, Gardiner, Wallkill, Walden, Montgomery, Goshen, Middletown, Warwick, New Millford, Hamburg, Deckertown, and Florida. At Middletown (a manufacturing and dairy center) there has been established a sewerage system which discharges into a small tributary of the Wallkill a total of about 865,000 cubit feet of sewage per day. The damage arising from this practice has been so great that it was made the subject of a special investigation by the State board of health of New York. In the twelfth annual report of that body is an account of the investigation, written by Mr. Charles C. Brown, formerly a professor at Union College, Schenectady. A part of Professor Brown's report reads as follows:

> The condition of the stream in the future, if left unattended to, will become rapidly worse, for the amount of pollution entering the stream is rapidly increasing. The sewerage system of the city of Middletown is practically but two years old [1891] and the proportion of houses connected with the system is still quite small. * * * Additional sewers are put in at frequent intervals and the city is steadily increasing in population. * * *
>
> This makes early attention to the improvement of the stream absolutely necessary. As far as Mohegan Brook is concerned, the trouble could be remedied by constructing an outlet sewer to Wallkill River. I believe the river is not large enough to take care of the amount of sewage discharged from the main sewer without the production of nuisance. Villages along the course of the Wallkill below Middletown are discussing the propriety of using the water for domestic purpose.

Since the date of this report, Middletown has increased to a city of 14,552 inhabitants, a gain of 21 per cent over the returns for 1890. The average daily water consumption is 2,000,000 gallons, and Mohegan Brook has been condemned by the courts as a sewage course, making it necessary for the city to provide a sewage-purification plant.

At Goshen the pollution of the small creeks which run through the village is remarkable. In a report made to the State board of health in 1890 Professor Brown stated:

> This brook at present receives much drainage from houses and business blocks in the village and nearly all the street drainage. But the headwaters of one branch of the stream furnish the water supply for the village, and what is left forms only a small brook, which must become very foul during ordinary seasons when there are no frequent heavy showers to flush it out. On my last visit I found the brook in this foul condition, throughout both its main branches in the village. * * *

I have no doubt that the condition of this brook is responsible to a large extent for the epidemics of zymotic diseases to which the village seems to be subject.

A water and sewerage system has been installed at Walden, a thriving dairying center of 3,147 inhabitants. The total daily water consumption is 80,000 gallons, but as the "combined" system of sewerage has been installed the discharge into the Ten Broeck and Wallkill is considerably more than the water consumption in stormy seasons.

Deckertown, N. J., having a population of 1,306, has installed an excellent water-supply system, and although no sewers have yet been laid a large amount of pollution enters the Wallkill. This forms another opportunity for future trouble arising from interstate pollution. The difficulties of regulating the New Jersey end of the watershed were recognized in the report of the engineering committee of the Merchants' Association of New York upon the Water Supply of the City of New York (p. 78). It was regarded as a "serious complication" in the way of adopting the Wallkill water for the city of New York, although these complications were recognized as due as much to other features of interstate regulation as to pollution.

Chester and Montgomery, villages of 1,250 and 973 inhabitants, respectively, are supplied with water systems, and the pollution of the river is by private drains and contaminated run-off water only.

New Paltz, a village of 1,022 inhabitants, furnishes a surprising amount of contamination, even though it possesses no system of sewerage. Plans were approved by the State authorities for such a system October 27, 1892, which provided for the ultimate disposal of the sewage in Wallkill River, with three main points of discharge. Although almost a decade has passed the system has not been laid, and in the interim extensive private sewers have been laid into the Wallkill in defiance of the State authorities.

ESOPUS CREEK.

A description of the drainage area of Esopus Creek appears upon page 63 of Water-Supply and Irrigation Paper No. 65, and current-meter discharge measurements which have been made at Kingston since July, 1901, are reported upon pages 64 and 65 of the same paper.

On Esopus Creek above the city of Kingston there is only incidental pollution from a few small hamlets, the effects of which upon the river are not important. At Kingston there is a system of sewerage, a part of which discharges directly into the stream. Previous to the installation of this system the State board of health sent its consulting expert, Professor Brown, to examine into the question of probable results of such installation, with especial reference to its effect at Saugerties, where at that time the water was used for drinking purposes by about 900 mill hands. A consideration of the ice industry and the damage that it would probably suffer by the installation of the sewers was included. After determining the physical characteristics of the river with reference to its natural advantages for assisting the process of

sedimentation, and taking into consideration the distance of the proposed outlet above Saugerties, Professor Brown made no very direct statement of the probable effect of Kingston's sewage, but finally recommended that all the sewage from the west end of the city be dumped into Rondout Creek, where it would be conducted more directly to the Hudson. This suggestion was not followed when the sewerage system was laid, and the results have been marked in Esopus Creek, so that it became necessary for the city of Kingston to construct a sewage purification plant. When that part of the system now under construction has been completed it will properly dispose of the sewage from two of the nine wards now discharging into Esopus Creek.

CATSKILL CREEK.

A description of the drainage basin of Catskill Creek appears upon page 61 of Water-Supply and Irrigation Paper No. 65. The records of current-meter measurements of the stream at South Cairo, N. Y., are set forth upon page 62 of said paper. The Catskill, with its principal branch, the Kaaterskill, is another of the western tributaries of the Hudson that is damaged only slightly by pollution. Here and there are small villages along the banks, none of which have sewerage systems, but which contribute manufacturing wastes and private-drain sewage in appreciable amounts, yet which as a whole have no marked effect upon the character of the water. Catskill, a city at the mouth of the river, is the only large place on it, and the pollution from there is carried quickly into the Hudson.

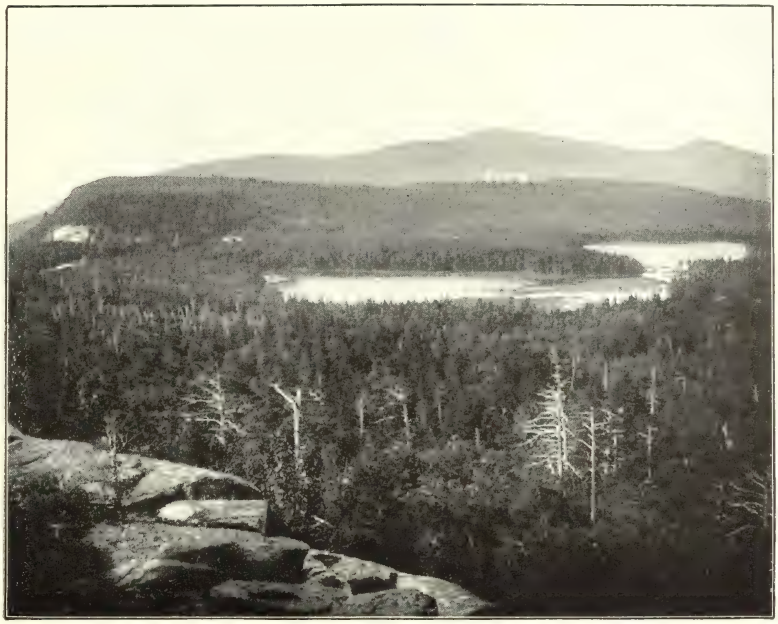
Hannacrois and Coeyman creeks and Norman Kill are not important from the standpoint of pollution.

MOHAWK RIVER.

This great western arm of the Hudson is nearly as widely known as the main river itself. The valley of the Mohawk was made famous in colonial times by Indian wars, and its beauty and the fertility of its land made it a favored line of western travel along which New England emigrants passed or within which they settled according to their tastes and resources. Cities along the banks of this river have grown into prominence, especially since the opening of the Erie Canal, and it is a favored section of the country, which is generally regarded as continuously prosperous.

Under the authority of the United States Geological Survey and the New York State engineer and surveyor, the Mohawk has been studied as has no other tributary of the Hudson. The results of this work are recorded in the Twentieth Annual Report of the Survey and in the State Report by Edward A. Bond, State engineer, made December 1, 1901, entitled Report on the measurement of the volume of streams and the flow of water in the State of New York.

According to the latter report the drainage area of the Mohawk is 3,400 square miles. Results of measurements of flow at a station



A. A LAKE IN THE CATSKILL MOUNTAINS AT THE HEAD OF THE CATSKILL RIVER, NEW YORK

From photograph in possession of American Museum of Natural History, New York City.

B. WINNISOOK LAKE, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

located at the New York State feeder dam, 4 miles below Schenectady, are expressed in the following diagram:

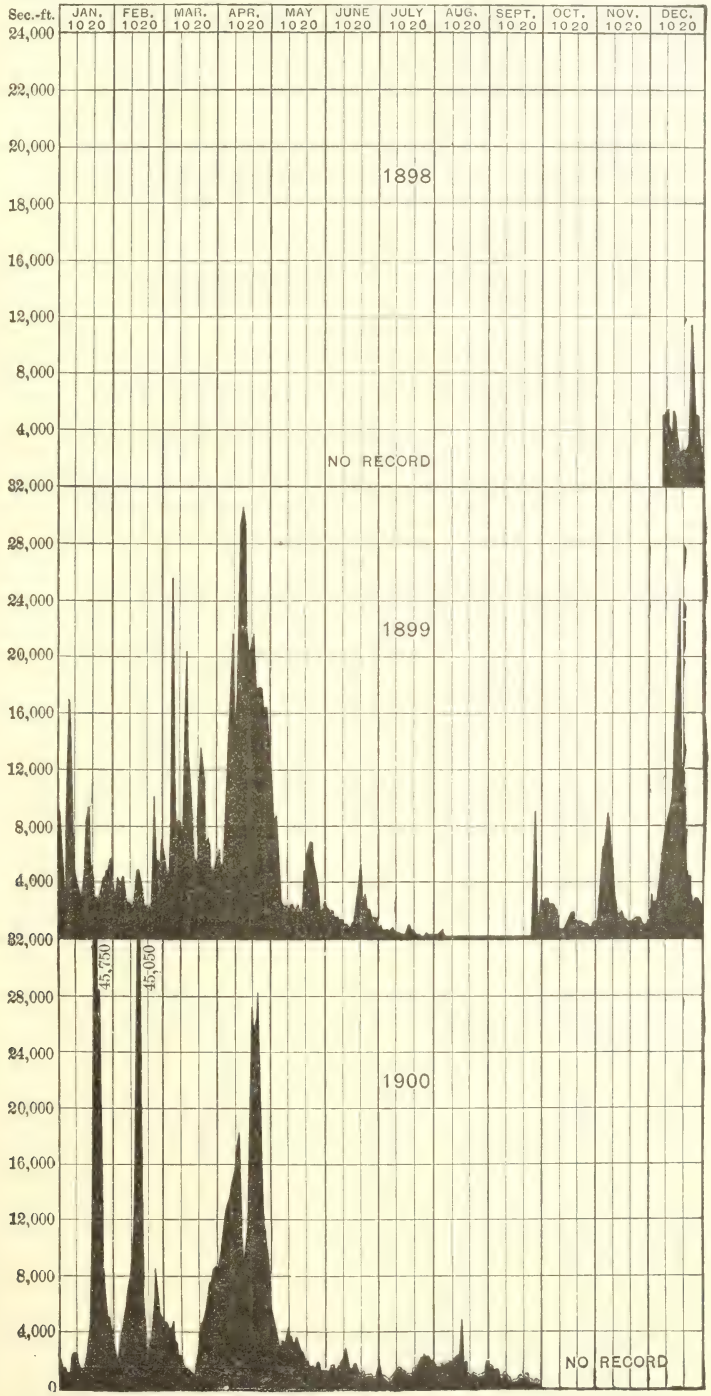


FIG. 2.—Discharge of Mohawk River at Rexford Flats, N. Y., 1898-1900.

Similar measurements were made at Little Falls, Herkimer County with results expressed as follows:

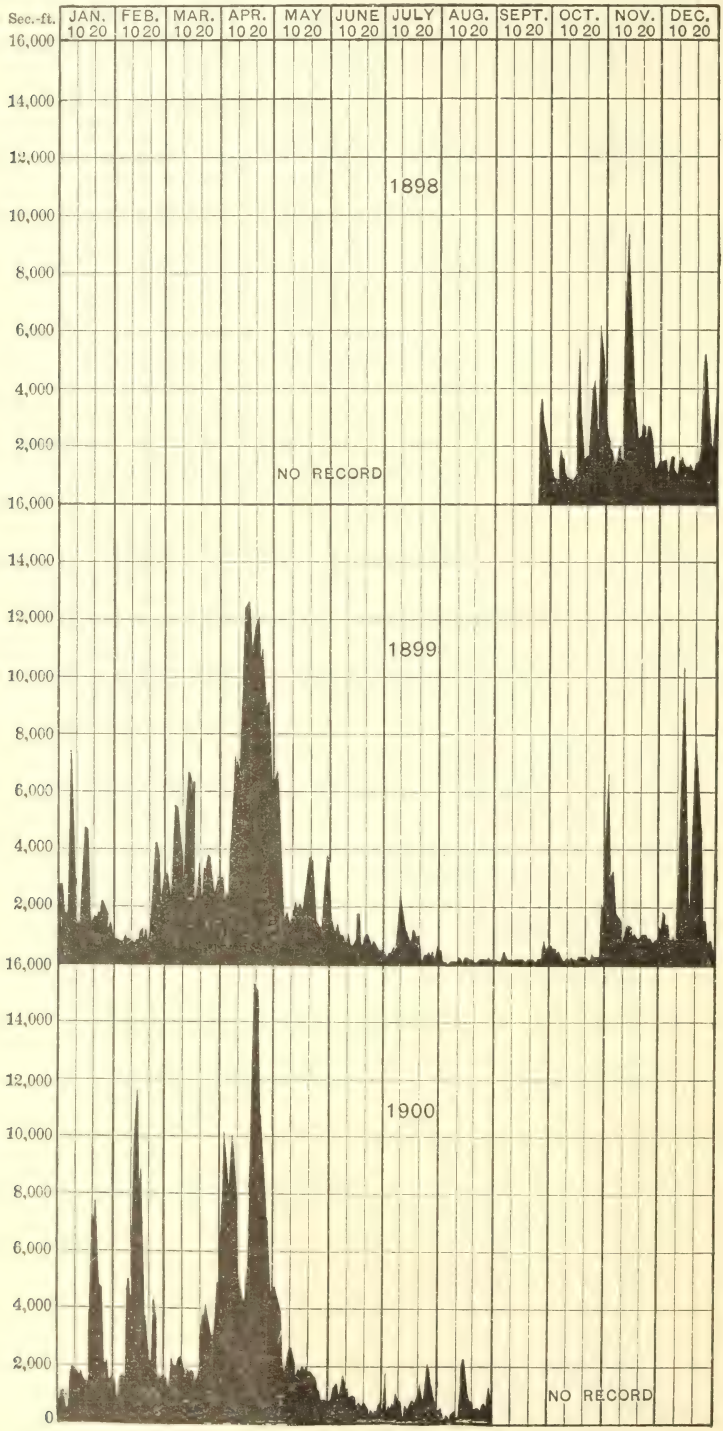


FIG. 3.—Discharge of Mohawk River at Little Falls, N. Y., 1898–1900.

The principal tributaries of the Mohawk are Schoharie Creek, with a drainage area of 974 square miles, East Canada Creek, draining 285.7, and West Canada Creek, the basin of which covers 584 square miles. This leaves to the main river and minor tributaries a drainage area of about 1,557 square miles. The centers of population on the Mohawk proper, from the point of view of pollution, are set forth in Table XVII:

TABLE XVII.—*Centers of population on Mohawk River.*

Name of municipality.	Population.		Water supply.	Sewerage system.	Sewered population.
	1890.	1900.			
Schenectady	19,902	31,682	Yes	Yes	31,682
Amsterdam	17,336	20,929	do	do	20,929
Fonda	1,190	1,145	do	do	1,145
Canajoharie	2,069	2,101	(a)	(a)	
Fort Plain	2,864	2,444	Yes	Yes	2,444
Nelliston	721	634	(a)	(a)	
St. Johnsville	1,263	1,873	Yes	No	
Little Falls	8,783	10,381	do	Yes	10,381
Herkimer		5,555	do	do	5,555
Mohawk	1,806	2,028	(a)	(a)	
Ilion	4,057	5,138	Yes	Yes	5,138
Frankfort	2,291	2,664	No	Partial	
Utica	44,007	56,383	Yes	Yes	56,383
Rome	14,991	18,343	do	do	18,343
Fultonville	1,122	977	No	No	
	120,422	162,277			152,000

(a) No returns.

The city of Schenectady, the first above Cohoes, is an important manufacturing center. It is provided with water from wells outside the city limits, a new supply which was installed when the city was

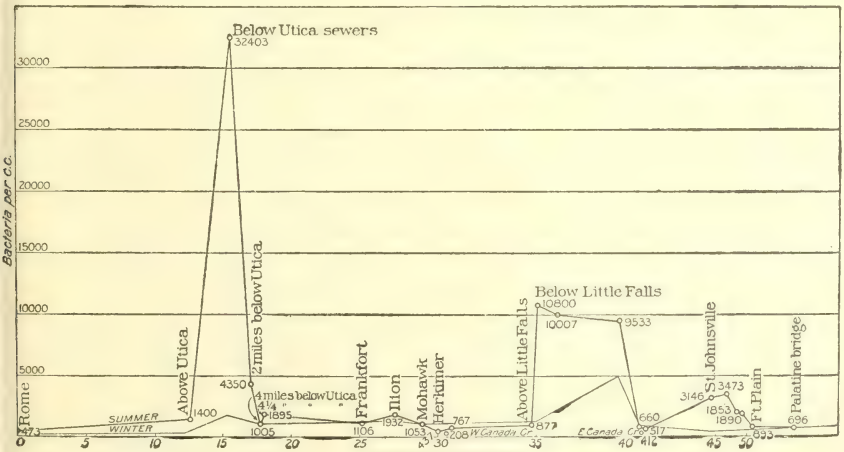


FIG. 4.—Diagram showing extent of pollution at various places along Mohawk River.

obliged to give up the use of the raw water from the Mohawk because of pollution from the cities above. There is also established a separate system of sewerage, from which, according to rough measure-

ments, there are poured into the river 6,000,000 gallons of raw sewage daily.

Amsterdam, a short distance above Schenectady, is also provided with a separate system of sewerage. The small villages of Fort Hunter, Fultonville, Fonda, Canajoharie, Fort Plain, and Nelliston follow in the order stated, each adding its increment to befoul the water of the Mohawk. At Fonda and Fort Plain the sanitary and storm sewers pour considerable sewage into the river, while at the other places there is only the incidental pollution common to unsewered towns.

At St. Johnsville there is provided a double system of water supply, one part of which is for domestic purposes and the other, drawn from a local creek, for fire and domestic purposes. The filthy impregnation of the soil is immense, and the report of the secretary of the local board of health states that, while the amount of sewage flowing into the river has not been determined, there is "plenty of it."

Little Falls has established a combined system of sewerage, which has been extended throughout the corporate limits. Herkimer has a separate system, which discharges about 200,000 gallons of raw sewage daily. At Ilion sewers have been extended practically throughout the corporate limits, and from them about 300,000 gallons are poured into the Mohawk. Farther up on the river is the large city of Utica, grossly polluting the river, and finally Rome, the sewerage system of which constitutes the head of pollution.

TRIBUTARIES OF MOHAWK RIVER.

Cobleskill is the only important point of pollution upon Schoharie Creek, while West and East Canada creeks have not at the present time sufficient pollution to warrant attention here.

The foulest branch of the Mohawk is Cayadutta Creek, a small stream entering the Mohawk from the north at Fonda. The nuisance occasioned by sewage from Gloversville and Johnstown has been of sufficient importance to demand a special investigation by order of the governor of the State of New York.

The following extracts are taken from the Eighteenth Annual Report of the State Board of Health of New York (pp. 85–100):

The undersigned residents of the city of Johnstown, N. Y., respectfully beg to present to your attention the unwholesome condition of a certain portion of this city, situated along East Main street and near the foot of Chase street, consisting of low, marshy land, having communication by a small stream crossing Chase and East Main streets, known as Prindle Creek, with Hale Creek, a large stream flowing for some distance parallel to East Main street, and about 350 feet distant therefrom, and emptying into Schiver's Pond, the waters of which flow into Cayadutta Creek and thence into the Mohawk River at Fonda, N. Y., 4 miles to the south. Into this locality and into the said Prindle Creek—the waters of which are very low during the summer season at the point where said creek crosses East Main street—empties a sewer about 12 inches in diameter, running

A. AUSABLE RIVER, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

B. DEVASEGO FALLS, SCHOHARIE RIVER, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

through a portion of East Main street west of said Prindle Creek, which conveys sewage from the houses along that portion of East Main street and from the houses along that portion of Fon Clair street, which intersects East Main street, being about 35 in number. Into Hale Creek, a short distance to the northwest, and at a point within 250 feet of the residences along said East Main street, empties another sewer of the same size, which conveys sewage from the houses and business places along the remaining portion of East Main street west of Prindle Creek, and from the houses on Glebe and a portion of East State street, which intersect said East Main street, in all being about 150 in number. These sewers have been laid a number of years, and their outflow has been recognized and pronounced by the local board of health to be a public nuisance, and orders have been issued by said board for the abatement of the nuisance. Into said Prindle Creek and the territory aforesaid at or near Chase street also empties a sewer pipe about 14 inches in diameter, running through Chase street and other streets to the south thereof, and which conveys the sewage from the houses on Prospect street, Whitmore avenue, East Clinton, Cady, and East Montgomery streets, a part of East State street, and a part of Fon Clair street. The three sewers mentioned convey all the sewage from the houses and business places in the southeastern portion of the city, comprising in all about 500 in number. The outlet of the said Chase street sewer is within 400 feet of the public school on East State street, at which there is a daily attendance of about 300 pupils.

The condition of affairs in this portion of the city has been frequently, during the past two years, called to the attention of the local board of health and the common council of the city, as the extracts from their minutes of proceedings hereto annexed and made a part of this petition will show, and although they have frequently taken the matter into consideration, no steps have been taken to correct or abate the nuisance and relieve the residents of that portion of the city.

The territory in the neighborhood where these sewer deposits are made is surrounded by residences of the better class, most of them recently built, and those along East Main street, east of the Prindle Creek, which number thirty-five, have thus far been unable to get any sewerage, because it is alleged that the bed of the Prindle Creek is not low enough to permit of sewering into that stream, and the local authorities have thus far refused to provide any other method.

In this connection it may be well to state that all the sewage of the city of Gloversville, and most of that of the city of Johnstown, is discharged, directly or indirectly, into the Cayadutta Creek, and thence into the Mohawk River at Fonda, without being treated, and it has been suggested that the territory referred to in this petition can be properly sewered by a pipe running through the bed of Schrivers Pond into Cayadutta Creek, and it is apparent that no special harm will come from this additional quantity of sewage thus disposed of. The undersigned, who live within the pernicious influence of this nuisance, which is admitted to be a nuisance by the local authorities, respectfully represent that the situation demands immediate action, that a loathsome stench pervades the locality under certain conditions of temperature, and that already, during the hot weather of this summer, this stench has been prevalent. Sickness has occurred which has been attributed by physicians to this cause. The nuisance increases in gravity every year, while the sewage more deeply impregnates and pollutes the soil.

The undersigned beg your excellency to lay the matter before the State board of health with instructions to investigate it and adopt such measures as shall without delay put an end to this nuisance. Efforts have been made for two years past without avail to accomplish this object, and we appeal to your authority to set in motion the measures which shall promptly relieve us of a distressing and dangerous pest.

[Signed by thirty-eight residents of Johnstown, N. Y.]

The report of Dr. F. C. Curtis, consulting expert, who went to investigate the conditions alleged in the above petition, is as follows:

Johnstown is supplied with sewers which provide for the house waste of a considerable portion of the city, all emptying into Cayadutta Creek. East Main street, referred to in the petition, is a continuation of Main street into a more recently built part of the city. The topography is such that it is impossible for a sewer from this section to connect with already existing sewers, as it lies at a considerably lower level. East Main street, which is built up with detached residences of a good class for some distance, has no sewerage outlet, the residences depending upon cesspools for their waste. To the southeast of this street the ground rises rather abruptly, and several streets, more or less built up, are laid out upon it. Coming down from this territory is a small stream, Prindle Creek, which traverses East Main street obliquely and flows across low meadows to Cayadutta Creek, or, rather, in its course, through Schrivers Pond. This is the natural drainage medium for the southeastern area of the city. The stream as I saw it, after prolonged rain, was a considerable one, but it soon dwindles to a very moderate flow of perhaps 10 gallons per second. Just before it reaches East Main street it crosses Chase street, which extends up the abrupt hillside for a few blocks and terminates at the bottom, as do all its parallel streets, in East Main street. In this Chase street is a recently laid 12-inch tile sewer which collects and carries off the sewage not only of Chase street, but of a number of lateral streets which branch into it. This sewer, with no provision for flushing it, terminates beneath a small bridge in the little stream, and as the volume of this stream is inadequate to carry away the sewage thus turned into it, this deposits directly at the sewer outlet and along its course, especially in the low meadow land on the other side of East Main street. It becomes a tortuous, uneven, open sewer, and by means of its improper use a serious nuisance, inevitably filling the surrounding atmosphere with offensive and unwholesome odors. There is no question of this, from my own observation, nor on the part of the health officer and citizens with whom I conferred.

In the Nineteenth Annual Report of the State Board of Health (pp. 74–76) Prof. Olin H. Landreth, who was engaged by the city of Johnstown to investigate the matter, reports in part as follows:

The only manufacturing waste of sufficient amount to warrant consideration in conjunction with the matter of sewage is the tannery and leather-dressing waste and refuse. There are at least 18 establishments in the city engaged in this business, employing in the aggregate about 750 men when in ordinary operation.

Returns were duly received from the majority of the concerns, representing over two-thirds of the total number of men employed and three-fourths of the total output, and means were taken to secure the best estimates possible for the remainder of the plants. The aggregate exhibit for all the plants representing those covered by both returns and estimates is as follows:

Number of men employed		740
Weight of hides per annum	pounds	5,600,000
Gallons of water per diem		150,000
Weight of lime per annum	pounds	725,000
Weight of alum per annum	do	230,000
Weight of salt per annum	do	1,500,000
Weight of oil vitriol	do	45,000
Weight of copperas per annum	do	6,000
Weight of bluestone per annum	do	600

Weight of muriatic acid	pounds	4,000
Weight of soda ash	do	50,000
Weight of hyposulphate soda	do	18,000
Weight of bichromate potash	do	12,000
Weight of fish oils	do	500,000
Weight of flour	do	100,000
Weight of logwood	do	1,500,000
Weight of Brazil wood	do	21,000
Weight of fustic	do	320,000
Weight of hypernic	do	110,000
Weight of quercitron	do	28,000
Weight of gambier	do	500,000
Weight of anilines	do	1,000
Weight of lactic acid	do	1,100
Weight of sal soda	do	15,000
Weight of alder wood	do	7,000
Weight of egg yolk	do	105,000

Accurate statistics of the amount of leather produced from the hides could not be obtained, but from estimates made by several individuals conversant with the business it is safe to conclude that the weight of leather, independent of the materials which it finally contains as filling and coloring matter, is less than one-half the weight of the hides used, indicating about 3,000,000 pounds per annum of refuse animal matter, chemical preservatives, and filth. Certain portions of this refuse material are preserved for utilization as by-products, but there is good ground for the estimate that not less than one-third of the above amount, or 1,000,000 pounds, and quite possibly 2,000,000 pounds, of the most offensive parts of this refuse from the hides is discharged into the creek. The returns show that of the water used by the tanneries less than 1 per cent is taken from the city supply, the remainder being about equally divided between creek water and deep-well water.

Of the chemicals tabulated, it is not to be inferred that all pass into the creek, nor that all that does pass enters the creek in the chemical form in which they are tabulated. A considerable portion of the chemical and coloring matter used is carried away in the leather, and much of what remains undergoes neutralization and other chemical changes before entering the creek, and also to some extent after entering the creek, as not all the establishments employ the same methods and chemicals nor discharge their refuse at the same time. The coloring and filling materials are largely retained in the leather, while smaller proportions of the active chemicals in the aggregate are so retained, and this latter class of materials forms the larger portion of the whole. Of the 5,800,000 pounds of chemicals and other materials used, not including the hides, my inquiries and study of the question lead to the conclusion that not less than 3,000,000 pounds are discharged after use into the stream either in solution or suspension (except as to the spent time), widely changed or neutralized, highly polluted and diluted. If to this we added 1,500,000 pounds per annum refuse from hides, estimated above, the aggregate of animal refuse, chemical, coloring matter, etc., discharges into the creek, independently of the water with which it is diluted, will be 4,500,000 pounds per annum, or 15,000 pounds per working day.

The general effect of pollution in the Mohawk and Hudson, from Rome to Albany, has been carefully studied by Prof. C. C. Brown and Dr. Theobald Smith, under the authority of the State board of health, and a statement of the results is made in the reports for 1892

and 1893, pages 531–547 and 680–736, respectively. Chemical examinations of water from Hudson and Mohawk rivers through Schenectady to Cohoes were made by Prof. William P. Mason and Willis G. Tucker, while the biological and engineering work was under the charge of Messrs. Smith and Brown, respectively.

The investigation shows in a striking manner the effect of pollution upon the waters of the Mohawk. Starting above Rome, where the water is practically normal both from a chemical and bacteriological standpoint, the samples taken at different points along the river to the mouth show greater or less pollution according as the points from which they were taken were near to or some distance below the outlets of sewers of the different cities. By way of illustration, the series of chemical analyses made by Prof. William P. Mason is reproduced in Table XVIII, taken from the Twelfth Annual Report of the State Board of Health of New York, pages 544–545.

TABLE XVIII.—*Pollution at different points on Mohawk and Hudson rivers.*

[The analyses are in parts per 100,000.]

	Chlorine.	Nitrogen as nitrites.	Nitrogen as nitrates.	Free ammonia.	Albuminoid ammonia.	Required oxygen.
At Rome	0.25	0.0000	0.0206	0.0045	0.0090	0.440
1. Just above Schenectady	.40	.0004	.0202	.0040	.0200	.485
2. Just below Mill Creek	.50	.0004	.0202	.0065	.0200	.440
3. Schenectady intake	.45	.0004	.0289	.0050	.0170	.425
4. Below New York Central bridge	.45	.0004	.0289	.0045	.0175	.430
5. Just below main Schenectady sewer	.45	.0005	.0288	.0040	.0195	(a)
6. Between Delaware and Hudson and highway bridges	.40	(a)	.0288	.0075	.0155	(a)
7. Opposite lower ice houses	.40	.0004	.0244	.0060	.0180	.395
8. One mile above aqueduct dam	.40	.0002	.0246	.0050	.0140	.365
9. Crest of aqueduct dam	.40	.0002	.0246	.0030	.0140	.355
Dunsbeck's ferry	.40	.0005	.0288	.0030	.0160	.330
10. Crest of Cohoes dam	.40	.0002	.0246	.0060	.0210	.355
11. Below Cohoes Falls	.40	.0003	.0290	.0130	.0255	.375
12. Waterford intake (Hudson River)	.25	.0000	.0123	.0045	.0170	.830
13. Troy intake	.25	.0000	.0041	.0040	.0150	.840
14. Below State dam (ebb)	.25	.0000	.0123	.0035	.0185	.610
15. A (ebb)	.25	(b)	.0123	.0040	.0140	.660
16. B (ebb)	.25	(b)	.0164	.0060	.0155	.620
17. C (ebb)	.25	(b)	.0164	.0030	.0180	.640
18. D (ebb)	.25	(b)	.0123	.0060	.0165	.670
19. E (ebb)	.25	(b)	.0123	.0060	.0160	.680
20. F (ebb)	.25	(b)	.0123	.0050	.0175	.685
21. G (east shore), ebb	.25	.0000	.0041	.0060	.0240	.900
22. G (middle), ebb	.25	.0000	.0041	.0050	.0215	.670
23. G, Albany intake (ebb)	.25	(c)	.0082	.0070	.0200	.570
24. H (ebb)	.30	.0000	.0000	.0115	.0140	.685
25. I (ebb)	.20	(b)	.0041	.0135	.0150	.695
26. J (ebb)	.25	(b)	.0041	.0125	.0160	.765
27. K (ebb)	.25	(b)	.0041	.0130	.0165	.620
28. L, Van Wies Point (ebb)	.25	(b)	.0041	.0115	.0170	.585
29. Below State dam (flood)	.25	.0010	.0000	.0030	.0185	.590
30. A (flood)	.25	.0000	.0041	.0055	.0160	.655
31. B (flood)	.25	(b)	.0000	.0050	.0165	.650
32. C (flood)	.25	(b)	.0000	.0055	.0170	.630
33. D (flood)	.25	.0000	.0000	.0060	.0150	.630
34. E (flood)	.25	.0000	.0041	.0045	.0175	.630
35. F (flood)	.25	(b)	.0000	.0055	.0215	.660
35½. Greenbush intake (flood)	.25	.0000	.0000	.0085	.0195	.675
36. G (east shore) (flood)	.25	.0000	.0041	.0070	.0215	.610
37. Albany intake (flood)	.25	.0000	.0041	.0075	.0185	.600
38. H (flood)	.30	.0001	.0041	.0120	.0205	.605
39. I (flood)	.25	(b)	.0041	.0110	.0185	.605
40. J (flood)	.30	.0002	.0082	.0120	.0170	.610
41. K (flood)	.30	(b)	.0082	.0125	.0170	.665
42. L, Van Wies Point (flood)	.30	(b)	.0082	.0090	.0165	.645

[a] Lost. [b] Trace. [c] Large trace.

With even more striking clearness does the record of numerical determinations of bacteria along the river show the compromising effect of pollution, and the positive tests for fecal bacteria to which the water was submitted by Dr. Theobald Smith make it unquestionably certain that waters polluted by domestic sewage retain the effects of fecal pollution, even beyond the point at which sanitary analysis would show an unpolluted stream.

Table XIX, which gives the results of numerical determinations on the Mohawk River, is taken from the same report as Table XVIII.

TABLE XIX.—*Pollution of the Mohawk River by bacteria, 1891.*

Date.	Number.	Time.	Number of bacteria per c. c.	Average of— Samples.	Average of— Plates.	Remarks.
July 29	1	7.00 p.m.	765	1	2	Rome water works dam, above city.
Do	2	8.00 p.m.	473	1	2	Below feeder dam at Rome.
July 30	3	8.45 a.m.	1,400	1	2	Above Utica; below bone works
Do	4	10.15 a.m.	32,403	1	2	Below Utica sewers.
Do	5	11.00 a.m.	4,350	1	2	Opposite Masonic Home, 2 miles below Utica.
Do	6	11.25 a.m.	1,005	1	2	About 4 miles below Utica.
Do	7	11.30 a.m.	1,895	1	2	About 4½ miles below Utica.
Do	8	3.00 p.m.	1,106	1	2	Frankfort, above New York Central station.
Do	9	4.55 p.m.	1,932	1	2	Ilion, below New York Central station.
July 31	10, 11, 13, 14	9 a.m. to 1 p.m.	.....	(*a*)	.....	Water roily from rain.
August 6	17	2.37 p.m.	1,503	1	2	Opposite canal lock at Mohawk.
Do	18	2.55 p.m.	437	1	2	Opposite Herkimer at lower bridge.
Do	20	3.50 p.m.	298	1	2	West Canada Creek.
Do	19	3.30 p.m.	767	1	2	One-half mile below mouth of West Canada Creek.
July 31	15	2.35 p.m.	877	2	4	State dam above Little Falls.
August 6	21	5.40 p.m.				
July 31	16	4.30 p.m.	10,800	2	4	Just below foot of falls, Little Falls.
August 6	22	6.15 p.m.				
August 7	23	10.00 a.m.	10,007	1	1	About 1½ miles below Little Falls.*b*
Do	24	12.10 p.m.	9,533	1	2	State dam, 5 miles below Little Falls.
Do	25	2.55 p.m.	660	1	2	Above mouth of East Canada Creek.
Do	26	3.05 p.m.	412	1	2	East Canada Creek.
Do	27	3.15 p.m.	517	1	2	Twenty rods below mouth of East Canada Creek.
August 8	28	10.15 a.m.	3,146	1	2	St. Johnsville, below creek draining village.
Do	29	10.55 a.m.	3,473	1	1	One-half mile below St. Johnsville, below rapids.
Do	30	11.30 a.m.	1,953	1	2	Three miles below St. Johnsville.
Do	31	1.15 p.m.	1,890	1	2	About 2 miles above Fort Plain.
Do	32	2.35 p.m.	833	2	3	Fort Plain, above New York Central station.
August 11	33	11.35 a.m.				
Do	34	12.50 p.m.	696	1	1	One mile above Palatine bridge.
Do	35	2.15 p.m.	304	1	1	Just above Palatine bridge.
Do	36	3.00 p.m.	273	1	1	Three-fourths of a mile below Palatine bridge.
Do	37	4.50 p.m.	560	1	1	At Sprakers, above rapids.
Do	38	5.20 p.m.	672	2	2	Three-fifths of a mile below Sprakers, below rapids.
August 12	40	9.20 a.m.				
Do	41	2.25 p.m.	164	1	1	Above Cayadutta Creek.
Do	42	2.30 p.m.	2,288	1	1	Cayadutta Creek.
Do	43	2.35 p.m.	306	1	2	One-half mile below Cayadutta Creek.

TABLE XIX.—*Pollution of the Mohawk River by bacteria, 1891*—Continued.

Date.	Number.	Time.	Number of bacteria per c. c.	Average of— Samples.	Average of— Plates.	Remarks.
August 12	44	2.40 p. m.	416	1	2	Three-fourths of a mile below Cayadutta Creek, below rapids, Fonda, and Fultonville.
Do	45	5.20 p. m.	283	2	4	Above Schoharie Creek.
August 14	47	12.40 p. m.				
August 12	46	5.45 p. m.	51	2	4	Schoharie Creek.
August 14	48	12.55 p. m.				
Do	49	3.15 p. m.	331	1	2	Opposite Akin station.
Do	50	3.30 p. m.	276	1	2	One-half mile below Akin.
Do	51	4.25 p. m.	231	1	2	Just above Amsterdam.
Do	52	4.50 p. m.	12,080	1	2	Chuctanunda Creek.
Do	53	4.53 p. m.	11,765	1	2	Opposite Wendell's drug warehouse, Amsterdam.
Do	54	5.03 p. m.	5,403	1	2	Opposite Armour's beef house, Amsterdam.
Do	55	5.13 p. m.	6,562	1	2	Just below Amsterdam.
Do	56	6.20 p. m.	2,904	1	1	One-half mile below last mill in Amsterdam.
Do	57	6.30 p. m.	9,812	1	1	One mile below last mill, Amsterdam, near garbage dump.
Do	58	7.00 p. m.	6,060	2	2	Opposite Cranes village, floating sewage.
August 15	59	9.00 a. m.				
Do	60	9.20 a. m.	1,104	1	2	One mile below Cranes village.
Do	61	11.20 a. m.	1,084	1	2	One-fourth of a mile below Hoffman's ferry.
Do	62	11.45 a. m.	710	1	2	One and one-fourth of a mile below Hoffman's ferry.
Do	63	1.50 p. m.	448	1	1	Above Fitchburg Railroad bridge.
Do	64	2.35 p. m.	656	1	2	Three and one-half miles above Schenectady.
Do	65	4.00 p. m.	1,634	1	2	One-fourth of a mile above Van Slykes Island, above Schenectady.
Do	66	4.45 p. m.	791	2	4	Above Glenville bridge, Schenectady.
August 17	68	10.45 a. m.				
Do	69	11.00 a. m.	444	1	2	Binnekill Branch above Edison sewer.
Do	70	11.05 a. m.	7,276	1	2	Mill Creek.
Do	71	11.10 a. m.	3,836	1	2	Binnekill Branch below Edison sewer and Mill Creek.
August 15	67	4.55 p. m.	1,145	2	4	Opposite waterworks, at intake.
August 17	72	11.20 a. m.				
Do	73	11.21 a. m.	440	1	2	Opposite waterworks, north side of channel.
Do	74	11.22 a. m.	432	1	2	Above New York Central bridge, opposite ice house.
Do	75	11.25 a. m.	312	1	2	Below New York Central bridge, opposite ice house.
Do	76	1.30 p. m.	196	1	2	Two hundred feet below sewer outlet; pond, sluggish current.
Do	77	1.50 p. m.	294	1	2	Above Delaware and Hudson Railroad bridge.
Do	78	2.00 p. m.	424	1	2	Below Delaware and Hudson Railroad bridge, opposite ice house.
Do	79	3.30 p. m.	296	1	2	One mile above aqueduct.
Do	80	4.10 p. m.	216	1	2	Aqueduct dam.

a Rejected. *b* Garbage dump, three-fourths mile above the locality of this sample.

NOTE.—Accidents happened to samples below the aqueduct, and reliable results were not obtained.

Table XX gives the results of tests made to determine the presence of fecal bacteria at the Albany water intake, together with the total number of bacteria in the samples.

TABLE XX.—*Pollution by bacteria of water at Albany water intake.*

Date.	Stage of tide.	Number of fecal bacteria.	Number of bacteria.					
			West side.		Middle channel.		East side.	
			Surface.	Bottom.	Surface.	Bottom.	Surface.	Bottom.
October 29, 5 p. m.	1.10 before low water	54	2,050	4,020	4,530	4,950	4,430	...
October 22, 2 p. m.	0.19 before low water	26	1,180	1,850	2,600	2,430	2,770	.....
October 15, 9 a. m.	0.21 after low water	22	3,290	3,590	5,170	4,390	8,200	.....
October 1, 9 a. m.	1.03 after low water	92	3,620	3,620	7,150	6,450	5,400	6,120
October 22, 5 p. m.	1.08 before high water	82	2,030	3,020	2,260	2,030	1,870	.....
October 15, 1 p. m.	0.53 before high water	32	2,840	2,730	3,220	3,960	4,170	.....
October 29, 1 p. m.	2.26 after high water	41	4,250	3,900	4,610	4,700	9,320	.....
October 1, 1 p. m.	0.18 after high water	26	1,980	2,090	2,950	5,280	4,090	.....

A further investigation of the water supply of Schenectady includes the determination of fecal bacteria, with special reference to *Bacillus coli communi*, the organism which is closely identified with intestinal contents. The localities from which the samples were taken are different, convenient, and favorable points along the Mohawk between Amsterdam and Schenectady. Table XXI gives the results of these investigations, taken from the Thirteenth Annual Report of the State Board of Health of New York, pages 731–732.

TABLE XXI.—*Determination of fecal bacteria in Mohawk water between Amsterdam and Schenectady.*

[The column "Number bacteria" gives the number of bacteria obtained by the gelatin-plate method. The column "Number coli" gives the number of *Bacillus coli communi*, and the column "Number fecal bacteria" gives the total number of the three kinds of fecal bacteria determined.]

DECEMBER 16.—FIRST SET.

Locality.	Number bacteria.	Number coli.	Number fecal bacteria.
Second lock	18,000	16	25
Below first rapids	20,000	.....	.....
Head Van Slykes Island	9,100	.....	.....
Below Sanders's house	6,800	.....	.....
Above Glenville bridge	22,000	13	19
Intake	13,000	45	49

DECEMBER 24.—SECOND SET.

Second lock	8,200	8	15
Below first rapids	.....	.....	.....
Head Van Slykes Island	.....	.....	.....
Below Sanders's house	6,100	.....	.....
Above Glenville bridge	5,700	12	12
Intake	5,900	12	12

JANUARY 14.—THIRD SET.

Opposite Akin, south side of river	16,000	7	7
Just below last Amsterdam sewer	27,000	.....	7
One mile below last Amsterdam mill	25,000	15	22

JANUARY 21.—THIRD SET.

Locality.	Number bacteria.	Nbmber coli.	Number fecal bacteria.
At Cranes village	12,000	3	3
One and one-half miles below Cranes village	16,000	13	13
At Hoffmans ferry	9,000	13	13
One and one-half miles below Hoffmans ferry	15,000	13	17

JANUARY 26.—THIRD SET.

At Fitchburg railroad bridge	18,000	25	29
At second lock	17,000	13	13
Half way from Sanders's house to Glenville bridge	20,000		
Eight hundred feet above Glenville bridge	14,000	16	19
Intake of waterworks	18,000	13	13

SCHENECTADY INTAKE.—DECEMBER 24.

7.15 a. m	3,700	23	31
11.30 a. m	5,900	12	12
4.00 p. m	4,900	31	37

The work outlined above was done in the early years of the last decade, when the science of bacteriology was still in its infancy. Since that time improved methods have shown that the bacteria isolated by Dr. Smith's famous process are not necessarily all fecal bacteria, but that there are other forms which respond to the same test. This does not reduce the weight of Dr. Smith's conclusions in the above case, however; for, taking into consideration the circumstances and conditions attending, there is good reason to believe that the greater part, if not all, of the organisms isolated by Dr. Smith were true fecal bacteria.

ANTHONY KILL.

Running in a general westerly direction from Ballston Lake, through Round Lake, Anthony Kill enters the Hudson at Mechanicville. Aside from the pollution that it receives from this village above the confluence with the Hudson, the only polluting area of importance is the camp-meeting settlement on the western border of Round Lake, and this has been rendered innocuous by the establishment of very satisfactory sewage precipitation works, described on page 371 of Sewage Disposal in the United States, by Messrs. Rafter and Baker. The permanent population of Round Lake is stated as about 400, and in summer, during some days, there are 7,000 people on the grounds. The source of water supply is Round Lake, and into this pond the purified sewage is discharged, but apparently without appreciable effect upon the water.

FISH CREEK.

Entering the Hudson at Schuylerville is Fish Creek, which takes a very irregular northwesterly trend from Saratoga Lake. The country

about the lake is of wide repute, having been at one time probably the most famous resort in the East, and is still holding its own with most of the watering places in the United States.

Saratoga Springs, with a permanent population of 12,409, and Ballston Spa, a village of 3,923 inhabitants, are situated within the drainage area of Saratoga Lake. Both municipalities are supplied with sewerage systems, and the extensive pollution of the lake is accurately described in a petition to the governor of the State of New York, signed by various residents of Saratoga County, from which the following extracts are taken:

The petition of the undersigned residents of the county of Saratoga respectfully shows as follows: That Saratoga Lake in said county is about 5 miles long and about 2 miles wide, and is about 4 miles from the village of Ballston Spa and Saratoga Springs, and that Saratoga Springs is a summer resort, visited by thousands of tourists every summer, and to Saratoga Lake is the chief drive and resort; that said lake has been for a great many years a prominent and attractive resort for fishing, hunting, and boating, and for the past few years offensive odors have arisen from the waters in the said lake near the shores, causing annoyance and breeding disease; that large numbers of fish have been picked up dead along the shores of the lake, and the shores thereof in certain portions are covered with filthy and noxious material, offensive to the eye and giving out offensive odors; that in the opinion of your petitioners, unless measures are taken to prevent the defilement of said lake, and its condition continues to grow worse, all the fish in the lake will be killed, and people will cease to occupy cottages on the shores, and it will cease to be attractive as a summer resort.

That the causes of defilement of the waters of the lake are various; that they proceed from the discharge of the sewage of the villages of Saratoga Springs and Ballston Spa into said lake, and from the discharge into said lake of chemicals and refuse from certain manufacturing establishments located in or near the village of Ballston Spa.

[Signed by 31 residents of the county of Saratoga.] [a]

The extent to which Fish Creek is affected by pollution is so far undetermined. It is probable that the actual damage in the stream is far less than in the lake, due, of course, to sedimentation. The report of Professor Landreth, made in response to the above petition, recognizes the importance of the offense and recommends that judicial proceedings be prosecuted to ascertain the exact amount of nuisance, and the responsibility therefor.

As a result of the action above outlined, the sewage-disposal systems of Saratoga Springs and Ballston Spa have been condemned and sewage purification must be established by both municipalities.

Victory Mills, a village of 795 inhabitants, is situated upon the creek a short distance above Schuylerville. It has no water nor sewerage system, and contributes an inappreciable amount of pollution to the river.

[a] Nineteenth Annual Report of State Board of Health of New York, p. 107.

DAMAGE TO WATER RESOURCES OF HUDSON RIVER SYSTEM BY POLLUTION.

It is not possible to estimate, with any considerable degree of accuracy, the amount of damage that has been done to the Hudson River system by sewage pollution. This is true, not because such damage is of incalculable extent nor because there is a lack of data, but by reason of the fact that there are so many features to be considered in this large area, and so many modifying conditions, that deductions must be drawn simultaneously from many different points of view and the resulting composite conclusions must ever be to a large degree modified by personal opinion. If we survey the different tributaries and note the points of contamination and the extent thereof we shall very soon realize that in nearly every stream there is such enormous dilution and so many opportunities for sedimentation that, taken individually, there is hardly any reason to believe that any material damage has been done. Going further, we look for the results of the concentration of all this sewage into a main water course, and find that that course is the middle section of the Hudson, which, as has already been stated, is of more value to the State of New York in its present contaminated condition than if regulations were enforced which would maintain its purity.

Summing up the total amount of raw sewage emptying into the river system, and taking into account the vast number of people living in cities along its banks, it would appear that the pollution is sufficient to entirely destroy the value of the water course and make the surrounding country an undesirable locality for many purposes; yet when consideration is taken of the fact that the amount of run-off water in this basin is sufficiently large to dilute this sewage so that in places it almost escapes detection, the actual damage done appears to be greatly modified, or, in the opinion of many, it becomes almost nil. This very question opens all the contested points concerning the amount or percentage of pollution within the safety limit; the idea of self-purification of rivers is brought to the front and with it questions as to the effect of the contour of river beds and the existence of artificial works, such as dams and mill ponds. In the discussion of different points of pollution in the preceding pages instances were cited of local nuisances due to contamination at near-by points, which contrast in a very confusing manner with the statement that off Poughkeepsie, where we might expect all this filth to give evidence of itself, Dr. Drown found what was, from a chemical standpoint, a very fair potable water.

In the results of bacteriological examination of the Mohawk by Dr. Theobald Smith we have seen that the high percentage of bacteria that appeared in samples of the water taken below cities gradually fell off as the points of pollution were left farther and farther behind.

When these results were plotted geometrically there appeared a series of crests and troughs in the curve, the distance between the crests corresponding exactly to the distance between points of pollution, measured at the same scale.

All these apparent paradoxes have their logical explanation, the disputed points being confined largely to minor details. It would, indeed, be an endless and unprofitable task to attempt to reconcile the different features which modify conclusions, and it will not be attempted here.

It is proposed to point out the losses and damages for which pollution is responsible, confining qualifications thereof to a few well-attested instances in which it is apparent that river pollution is less expensive than the avoidance of it. There are many cases in which the cost of purifying sewage before turning it into a river, or the expenses entailed in securing some other place of final disposal, far exceed the cost of providing a pure-water supply from highland or other sources, and in such cases it is manifestly better, if there are no other rights to be considered, to use a stream as a sewage course rather than a source of water supply. Such instances should be treated from the standpoint of general public economy, every apparent consideration being taken into account.

WATER POWER.

It has already been stated that damages to water-power interests in the Hudson drainage area are not, comparatively speaking, large. There are, indeed, a few mills that have been obliged to give over the use of river water in various manufacturing processes because of impurities it contains, but the loss entailed does not appear to be serious. Neither does the future promise any remarkable change in this respect. Without doubt, new sewerage systems that are approved from time to time by the State commissioner of health will be provided with means of purification if the installation of such systems promises any great increase of river pollution.

There are few cases in which mill ponds have become public nuisances by reason of deposits of sewage upon the banks, but such will be taken up under the consideration of damages to realty values.

ICE.

The Hudson River ice crop has a national reputation, yet few people realize its extent, and fewer can locate the points at which storage houses are gathered. In the April number of the Ice Trade Journal for 1901 nearly four pages are occupied by a list of ice houses along this river and a statement of the amount stored in each. The crop depends entirely upon the winter's temperature, and the amount of ice that is available for harvest varies accordingly. During the winter of 1900–1901 there were cut and stored 4,606,800 tons, this being

the largest crop ever gathered. During the preceding year there were stored only 1,430,670 tons, which, although large in itself, seems small when compared with the enormous amount harvested in the succeeding winter.

There seems to be no special center for the industry, the field extending all along from Schuylerville, past Cohoes, Waterford, and Troy, nearly down to the limit of salt water influence. On Rondout, Esopus, Catskill and other creeks there are large ice houses, and from certain lakes, such as Rockland, Croton, and Mahopac, there is gathered a considerable harvest, 230,000 tons being cut from these three lakes during the past winter. By far the greater amount, however, comes from the main river.

Sufficient data have been presented to show how great, even in the most unfavorable years, is the value of the Hudson River as a source of ice supply. It has been stated in preceding pages that pollution in a river is a damage to the ice industry, and that, even though recent research indicates that the typhoid bacillus does not survive during long periods when locked in ice, public use of this commodity when polluted with sewage will not be tolerated. A little reflection will show how worthless is a polluted stream or lake as a source of ice supply. Modern biology has found means effective for the purification of contaminated water. Such means are not applicable to ice, and thus polluted ice is, or should be, a total loss; it can not be sterilized nor in any way relieved of its dangerous qualities. With the ever-increasing use of this article in and upon our food there is a necessity that greater care be taken as to its source. The absence of typhoid fever bacilli in polluted ice is by no means a guarantee of its safety for domestic use. The dangers are well expressed in the following paragraph, taken from an article by James M. Anders, M. D., LL. D., of Philadelphia:

> While I shall endeavor later to emphasize the potency of impure water, especially when bacterially contaminated, in causing certain diseases, I desire at the outset to insist that the deleterious and devitalizing effect of imbibing such water, upon the general health of the community, is practically inconceivable. By lowering the resistance to that large class of infectious diseases, its indirect influence as a causative factor must be considerable, not to speak of the suffering occasioned by the habitually depressed and weakened systemic condition thus engendered. Much inconvenience and ill health caused by impurities in the drinking water originates primarily from the alimentary tract, and is due to gastric and intestinal disturbances. The ingestion of contaminating materials may be a cause of dyspepsia or diarrhea, and most probably also renders the system receptive to the invasion of the bacillus coli, the bacillus of Shiga, and other pathogenic organisms, and this *quite independently of any pollution of the drinking water by the disease-producing germs themselves* [italics by M. O. L.].—American Medicine, March 29, 1902, p. 503.

Above Albany were cut, last season, 502,700 tons of ice. By far the greater part of this was taken below the mouth of the Mohawk and in that river itself. At Crescent, a bend in the Mohawk, a few miles

below the outlet sewers of Schenectady, the reports show a total crop of 163,000 tons. From the mouth of the river, where the pollution from Cohoes, Waterford, and Lansingburg is most dangerous, were taken 200,000 tons more, and below Troy and Watervliet the harvest amounted to about 75,000 tons. The water taken from practically these same points was found by Dr. Theobald Smith to contain fecal bacteria.

South of Albany, within 4 miles from the outlets of the sewers of that city, and at Rensselaer there were harvested during the season of 1901 over 300,000 tons of ice. The water in the Hudson above Albany is now being purified for potable use in that city, because the citizens found by costly experience that it could not be used in its raw state. What, then, must be the condition of that water shortly after the sewage of 101,617 more persons has been added to it?

In spite of the conditions outlined above, this river is the principal source of ice supply for the great metropolitan area, and although the value of the artificial-ice business is growing at a rapid rate, due in part to distrust of ice from the Hudson and other polluted sources, such has been the growth in the demand for ice that the market for this contaminated product remains undisturbed. It can not, however, remain indefinitely firm, and when the facts have been placed before the public with sufficient intensity the value of the Hudson as a source of ice will be materially damaged. Reference to the report of Prof. William P. Mason made to the Manufacturers' Association of Brooklyn will show very clearly the character of Hudson ice. He substantiates the belief that the formation of ice eliminates impurities to a certain extent, but found upon testing samples of ice taken from germ-polluted fields in the Hudson River, just below the junction of the Mohawk River, that certain disease germs were still alive, and condemned this ice as wholly unfit for use in cooling beverages. Typhoid germs were not killed, as was proved scientifically. He cited the case of a typhoid epidemic which spread from Schenectady to Albany, the Mohawk River carrying the typhoid germs down to its mouth, polluting the ice formed in the Mohawk, whence the ice supply of both cities was obtained. In this manner both cities suffered with a typhoid epidemic.

The association is to present petitions to both the State and city health boards, asking that some steps be taken to prevent the polluted ice being sold in this market.[a]

The above declaration from so distinguished an authority can not be barren of results, and the consequent action taken by the Manufacturers' Association can not fail to be adverse to the use of ice cut on the Hudson. It will produce no widespread revulsion, nor will the ice industry of the river be destroyed in a season, but there can not fail to be a gradual concurrence in the idea that Hudson River ice

[a] Abstract in Municipal Journal and Engineer.

is an inferior article, the price of which will be forced lower and lower by the active commercial spirit of this country. It will not be necessary even to advance hygienic considerations beyond the point at which they are able to beget distrust in the market of New York.

According to prevailing prices, the last Hudson ice crop is worth at least $8,000,000. In unfavorable seasons the pure article from that source could not fall below an annual value of $3,000,000. For what fraction of this sum annually could all the Hudson Basin sewage be purified?

WATER SUPPLY.

The estimation of loss of capital in a river which is polluted to the degree apparent in the Hudson can not be brought to a very fine point of accuracy. If we were to consider the effect of sedimentation, and figure out all the other factors that are effectual in the so-called self-purification of rivers; if we were to consider the amount and character of the sewage and the dilution thereof, we might be able to reach an approximate figure of damage, and even then it would be of little more value than the rough résumé that can easily be made. If the science of water purification were in the same state in which it was a quarter century ago the problem would be more simple, for at that time there were no well-established, reliable means of purification in common use in this country. To-day, however, the purification of polluted water for domestic use has reached that state of perfection at which it has become the practice of reputable engineers to take polluted water from a stream at the very doors of the city and purify it, rather than to expend large sums of money in conserving an unpolluted supply miles away in a sparsely settled district. The case of Philadelphia at the present time is pertinent: On January 4, 1901, the United States Senate Committee on the District of Columbia convened at New York to discuss with the engineering profession the question of filtration of water supply at Washington, D. C. Mr. Rudolph Hering, M. Am. Soc. C. E., stated in his testimony with reference to the experience of Philadelphia that, in 1883, he was engaged by that city to make studies for the new city water supply. As the subject of water filtration was not fully developed at that time he recommended an unfiltered water, taken from the Blue Ridge. More recently, during his connection with the Philadelphia waterworks, he recommended the Schuylkill River and the Delaware, because of the fact that this water could now be made sufficiently pure for use, and under the circumstances it presented a more feasible plan from every standpoint, for both present and future generations.

It becomes necessary then, in considering pollution in a river from the standpoint of water supply, to make allowance for the fact that the water can be purified and that its precedent pollution does not constitute a complete loss of resource. Under such circumstances

the actual amount of damage done consists of the difference between the cost of pumping raw water for direct use and the cost and maintenance of a filtration system.

There remain certain rivers, the pollution of which seems altogether unnecessary, which could be preserved in approximately their normal state, yet which receive sewage enough to damage their water supply values. Such streams are the Wallkill and Batten Kill. In such instances, where the cost of sewage disposal would be comparatively small, there seem to be no compensating factors to offset the damage done to the river as a source of water supply, and pollution becomes needless and unwarranted.

The cities on Hudson River proper that now derive all or a part of their water supply from the river by pumping are Poughkeepsie, Catskill, Hudson, Albany, Rensselaer, and Troy, including the recently annexed Lansingburg. In all of these places except the latter the water is filtered, and in the latter case only a part of the supply is derived from the Hudson.

The filtration systems at Poughkeepsie, Catskill, and Hudson were established before the present knowledge concerning the action of filters was very clearly defined, and there was no idea of purification of the water in the sense that that term is now understood by the profession. The main object of these filters was that of clarification, i. e., an elimination of the sediment which is carried down the Hudson in large quantities, and if there had been clear water in the river the chances are that neither of these filters would have been installed at that time. The cost of construction in these three cases can not, therefore, be charged against the debt of sewage pollution. Whatever may have been the initial cause of installing the Poughkeepsie, Hudson, and Catskill filters, it is apparent that they are at present maintained for the added purpose of biological purification as well as that of clarification. It would be quite unlikely that, should the waters of the Hudson become free from sediment, the filtration system would be abandoned in the face of all the sewage coming past their respective intakes, so that it is a fair position to assume that pollution is partially responsible for the expense of maintenance of these filters. While this section of the Hudson is under consideration it may be of value to pursue this subject with the help of a projected enterprise that emphasizes in a forcible manner the damage that must be faced in such rivers.

One of the most thoroughly discussed water-supply problems that has been before the public for many years is that of the present and future supply of the city of New York. In August, 1899, Mr. William Dalton, commissioner of water supply for the city of New York, startled the city and convulsed the engineering profession by recommending that the board of public improvements approve a forty-year contract with the Ramapo Water Company, under which the city

was bound to buy at least 200,000,000 gallons of water daily at a cost of $70 per million gallons. The excessive cost of the water was only one item of disadvantage to which the city was to be subjected by the execution of the contract. The immediate opposition which was developed, headed by Comptroller Bird S. Coler, caused a stay in the proceedings, during which time the matter was investigated by the comptroller and independently by the Merchants' Association of New York, a body whose power in city affairs and in the establishment of sound corporate policy has ever been notable. An organized staff was made up from the association and, aided by the comptroller and Governor Roosevelt, every phase of the proposed swindle was laid bare. In addition to this, investigations were made into every branch of the water-supply question, and the report that was issued is one of the most valuable of the recent publications on this subject. The engineering committee, under the leadership of Mr. Rudolph Hering, instituted among other things an investigation into the available sources of supply for the city and, with their consulting engineer, Mr. James H. Fuertes, carefully considered every adequate source of supply in the State, finally deciding that the most feasible plan was the pumping of the water from the Hudson River itself, at a point just above the city of Poughkeepsie, where a supply of 1,500,000,000 gallons daily was easily available if proper compensating reservoirs were constructed in the Adirondacks for replenishing the river during dry seasons.

It is the consideration of this extensive project and the analysis of the estimates of cost and maintenance thereof that give the inquirer his first adequate idea of the loss which may arise and the damage which may accrue to the resources of the Hudson River through pollution. These estimates were based upon a proposed supply of 500,000,000 gallons daily, which is probably the maximum additional supply that will be required by the city during a long term of years. The minimum cost for such a system would be $72,374,000, of which $32,557,000 is for filters and pumping plant, largely made necessary by sewage pollution. The minimum cost for the water at this rate would be $30.39 per million gallons, of which $4, or about 13 per cent, is the amount expended for filtration. In the estimated annual cost of operation and maintenance is included $730,000 for cost of filtration. If in the course of years it should become necessary to develop such a system to its full capacity the cost of overcoming the effects of sewage pollution would increase accordingly. Thus it may be seen that if at any time in the future the city of New York should adopt the Hudson supply and use the maximum amount, the polluted condition of the river would necessitate an annual expenditure of at least $2,000,000 in addition to the initial cost of establishing so gigantic a filtration system.

The history of the Albany water supply is closely linked with the

history of pollution in the Hudson at that point, and the recent establishment there of what was, at the time of construction, the largest filter in the country is a direct consequence of the sewage in the river from the Albany sewers as well as from the numerous places within a short distance above. In the year 1873 it became necessary to augment the gravity system of water supply then in use at Albany, and an intake was placed in the Hudson and water was pumped therefrom into the reservoirs, to be mixed with the upland water. With the growth of the city more and more was pumped from the Hudson, until at the present time the pumped water exceeds in amount that taken from the old gravity system. Throughout the history of its water system Albany has employed eminent authorities to guide her steps, and the establishment of this Hudson intake appears to have been undertaken advisedly. When, after the lapse of some years, there arose a feeling that all was not well with the water, fears were again quieted by the reassurances of a distinguished gentleman. Whatever deleterious material might be poured in the river at Troy, 4 miles above the intake, would be, said the expert, rendered entirely harmless through various influences, among which were sedimentation, dilution, and oxidation. The fact that the death rate and morbidity from typhoid fever was high seemed to have no bearing upon the case, nor was there, in the opinion of the city's advisers, any significance in the fact that epidemics at Albany followed those at Troy, Schenectady, and other places. The eminent authority maintained his position and, we believe, sticks to his conclusions to-day.

In 1885 Prof. William P. Mason, in a report to the water board, showed very clearly the deplorable condition of the water and condemned it in unmistakable terms. From that time until 1896 there was a series of efforts to provide a new supply, all of which failed, until in July, 1897, it was finally decided to filter the water from the Hudson. Under the direction of Mr. Allen Hazen, M. Am. Soc. C. E., a covered filter was constructed at a cost of about $500,000, and the expense of operation is about $4.19 per million gallons, or about $20,000 annually. The results have already been more than sufficient to pay for the cost of the construction. The death rate from typhoid fever has been very materially decreased, and the good effects of the filtration system remain undisputed.

Troy up to the present day is drawing a part of its water from the Hudson and delivering it to its citizens in the raw state, and for years efforts have been made to obtain a new supply, until there seems now to be an assurance of better water. This city has been even slower than Albany to realize the damaging effects of Hudson water, and the indifference of the citizens there has called from Prof. William P. Mason the statement, made during his testimony before the Senate Committee on the District of Columbia, that "up in Troy anything short of soup would be satisfactory." The new water supply, which the bet-

ter element in Troy has at last succeeded in pushing to a successful issue, is to be conserved in sparsely settled districts east of the city. It will furnish, when fully developed, about 40,000,000 gallons daily, and the present plans contemplate an expenditure of $1,250,000.

These are the actual water-supply expenditures which have been made necessary by sewage pollution in the main river and also the costs which would be incurred should the plan recommended by the Merchants' Association for the future supply of the city of New York be adopted. It is clear that the Hudson River along this section must necessarily be polluted, and the expense of water filtration must always be regarded as one of the running expenses to be perpetually maintained in the Hudson Valley. There is no possible way of overcoming it, and it must be considered in a summary of this character. It may be contended that the free drainage of cities into the Hudson is a privilege which compensates for the disadvantages that arise from the damage to the natural water resources. A little reflection will show that such a contention is idle, and that, after allowing for all the items which constitute the credit side of the present account, we shall find that the pollution of the Hudson River is very costly.

The eastern tributaries of the Hudson are not damaged to any great extent by pollution, except the Hoosic and Batten Kill. At the present time the water from the former river is badly contaminated, yet not sufficiently to damage any of the resources which it has, up to this time, been called upon to yield. The ice industry upon the river is not worth considering, and the only resource which is damaged is the water supply. If there should ever be a demand for the water in the basin of the Hoosic it would be necessary to resort to filtration under the present conditions. Pollution in the Hoosic is positively needless, and its existence there is damaging to a resource which, properly cared for, would be one of the fairest in the Hudson River basin. The same statements are true with reference to Batten Kill. Although the contamination of this stream is less than that of the Hoosic, there is sufficient to cripple its usefulness as far as the use of its raw water is concerned.

Similar statements may be made concerning the western tributaries. The Wallkill is a river which seems excellently adapted for water supply, and if proper care were exercised it might be possible for each municipality along its banks to establish its water intake at almost any convenient point along the river and use the water with safety.

There is little to add concerning the Mohawk. We have seen that it is the river which contains the greatest relative amount of pollution of all those tributary to the Hudson, and that the sewered population along its banks numbers 152,000. The only cities which have of late attempted to draw their supplies from the Mohawk are Rome, Schenectady, and Cohoes. Above the first mentioned city the water is fairly satisfactory from a sanitary standpoint, but at Schenectady

LOG JAM IN ADIRONDACK BROOK, NEW YORK.

From photograph in possession of American Museum of Natural History, New York City.

the work of Dr. Theobald Smith was too conclusive to admit of any doubt concerning the dangerous quality of the water. Consequently that city has been obliged to abandon its intakes in the river and is now supplied by driven wells. Cohoes is still contented to drink from the cesspool of its neighbors.

It would, no doubt, be impossible to make the Mohawk pure. If all sewage pollution were eliminated, it is probable that the surface drainage of so populous a country would unfit the water for use in its raw state as a domestic supply. Certainly, if such is not the case at present it will be true within a few years. The present danger is that the conditions along the Mohawk may approach those of the Passaic; it will be remembered that the increase of population here is greater than at any point that we have considered in the Hudson drainage area.

The water-supply damages cited on the Mohawk, then, are total unfitness of the stream as a source of raw supply and necessary abandonment of an intake by the city of Schenectady.

The character of Saratoga Lake, and the use to which it has been put, makes its use as a water supply undesirable. It might, of course, have been used for this purpose before it became so polluted, but, as it is a part of the great summer resort, it is natural, and almost imperative, that it should be given up to recreative purposes and as such it becomes unimportant from the standpoint of water supply.

REALTY VALUES.

There are many places in the Hudson drainage area that have been made undesirable by sewage pollution, but in the majority of cases they are so very close to sewer outlets that nothing else could be expected, and the surrounding neighborhoods have been adapted to meet such conditions. Such places must ever exist—it is necessary for every city to have its garbage area and dust bin, and it has become the custom to develop these surroundings in such a way that the interests involved do not suffer materially by the existence of that which, in residential districts, would seriously impair established values. There is no place on the Hudson where the condition approaches that upon certain parts of the Passaic, where land has been reduced to no value and localities have been brought to a standstill. The region about Johnstown on Cayudutta Creek and the shores of Saratoga Lake have been fast approaching that condition, but up to the present time there has been only a relatively small amount of realty damage.

The law reports of New York State contain, here and there, cases arising out of polluted conditions in this area, the most important of which are the following:

Supreme court, May term, 1891 (67 Hun, p. 294); Joshua Demby *v.* City of Kingston, N. Y.:

The plaintiff and wife were tenants by entirety upon two lots, through

which ran a stream that was polluted by city sewers. Plaintiff was obliged to cover stream and to incur considerable expense to get rid of nuisance, and finally sued the city for damages and prayed for an injunction against further pollution.

The city held that it was not responsible, as the nuisance was caused by private connections in a sewer built for storm water, and the city could not go upon private property and remove them. The award of the jury in the lower court was affirmed, the amount being $524, and a permanent injunction was issued.

Supreme court, September term, 1893 (71 Hun, p. 232); Simon Schriver *v.* Village of Johnstown:

The case was presented on appeal from the lower court, in which the jury awarded $2,000 damages, and the court issued a permanent injunction. A part of the opinion of the supreme court is as follows:

> The maintenance by a municipality of a permanent system of sewers, through which sewage passed into a natural stream and pond of private ownership, causing pollution and sediment, presents a case for perpetual injunction and normal damages. The measure of damages in such a case is the depreciation of rental value.

The estimated rental value of the pond was $600 per annum. Of this $400 was still available under the polluted conditions, leaving a balance of $200 for which the city was responsible. Damage for ten years, amounting to $2,000, was affirmed, and the permanent injunction was continued.

Supreme court, appellate division, May term, 1897 (17 New York, p. 207); Moody *v.* Saratoga Springs:

An appeal by defendant from verdict in lower court in favor of plaintiff. Damages were awarded and an injunction was issued.

The principal contention before the court of appeals was that the village was not responsible by reason of the act of the legislature which authorized the construction.

A part of the opinion rendered by the higher court reads:

> The purpose of chapter 149 of Laws of 1885, providing for the extension of the main sewers of Saratoga Springs, was to promote the interests of the village, and the village is liable to the owner of premises near a creek into which said extension is discharged from the injuries resulting from the pollution of air and water caused by such discharge.
>
> An act which authorizes the extension of a sewer authorizes its use, but such use must not result in a nuisance or occasion injury to the legal rights of others.

In conclusion, having considered as minutely as seems advisable the different sources of pollution in the Hudson River basin, and having indicated in a brief, summary manner its effect upon the natural water resources, it now remains to determine what may be the future of these resources and whether pollution will continue to grow or be checked by popular disapproval and consequent legislative enactment.

The whole question has been modified by the successful introduction of filtration for water supplies. It is manifest that the most potent damage that is ordinarily done to the resources of a stream is its destruction for use as a source of water supply, but, having overcome this difficulty by the introduction of filters, it is more than likely that the tendency will be toward toleration of a certain amount of pollution, and the expense of filtration will be regarded as a fixed charge upon the community at large.

The growing use of sewage purification processes has also a bearing upon the pollution question. The effluent from sewage purification works, while properly and theoretically harmless, can not at all times be depended upon to thoroughly eliminate all the pathogenic bacteria that are found in it. There must be laxities, arising in even the most carefully conducted sewage purification plants, that are entirely unavoidable. Sewage will pass through the purification process and will not be treated so efficiently as the process of purification will permit nor so carefully as the diligence of those in charge would seem to warrant. Under such circumstances it is clear that we can not place sufficient dependence upon sewage purification to warrant us in using for potable purposes the raw water from a river into which such effluent is emptied.

Natural surface drainage, too, is to be considered. Upon rivers having large cities along their shores a certain amount of pollution must arise from the natural drainage of occupied land, and this may be a detriment to the river. Such contamination is unavoidable, and is certainly not so important as that from city sewers, yet it is true that the uncertainties that arise make it necessary to avoid the use of water so contaminated for domestic purposes without filtration. So it appears, as already observed, that the tendency will be to assume that the contamination incident to the surface drainage of occupied land and the effluent from sewage purification works is a necessary and unavoidable evil, and to consider that the diminution of natural water resources by this means is one of the prices which society must pay for its social and economic development.

The above applies to rivers with considerable population in their immediate drainage areas. The pollution of upland streams in sparsely settled districts must, however, be regarded as needless, and as a crime against the community. The greater part of these areas possesses little value from an agricultural standpoint. Under the present conditions they are principally useful in raising forests. The highest development of their natural values would arise by setting them aside as regions for the conservance of water. In this way the forestry and water problems could be dealt with coincidently, and the adoption of such as a public policy would be wise.

The damage to ice interests by sewage pollution will, in the course of years, settle itself. The manufacture of ice is a growing industry,

and when the time shall come that polluted ice is no longer tolerated, the use of artificial ice will become universal. The rivers that are now used as ice fields are, in the majority of cases, those that are polluted to a greater or less extent, so that the damage to that part of the water resources must also be assumed in the same spirit as that just described with reference to water supplies. It will, in this case, be a surrendering of certain natural sources of wealth for an equal value in a new industry.

Within the area covered by this brief analysis there are a few interstate features, although the questions involved are not now of local interest. We have seen that a part of the drainage area of the Passaic extends over into the State of New York and that the Hudson River Basin comprises small parts of Vermont, Massachusetts, and New Jersey. What the future may bring forth in these places with regard to interstate pollution is a matter of conjecture, yet if the cities of North Adams, Mass., and Bennington, Vt., should grow sufficiently to pollute the Hoosic River to the same extent that the Passaic or Cayadutta Creek is now polluted, there would arise damages to different interests in the State of New York which the courts of that State could not correct. What the result would be is uncertain, for there is not yet any well-defined process nor any established practice by which such matters could be easily adjusted. There is a national authority over common interstate matters, and there should be an equal control over the interstate features of rivers whose courses lie within two or more States.

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The DIRECTOR,
UNITED STATES GEOLOGICAL SURVEY,
WASHINGTON, D. C.

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Water-Supply and Irrigation Paper No. 73 Series J, Water Storage, 7

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

WATER STORAGE

ON

SALT RIVER, ARIZONA

vdermilk.
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BY

ARTHUR POWELL DAVIS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

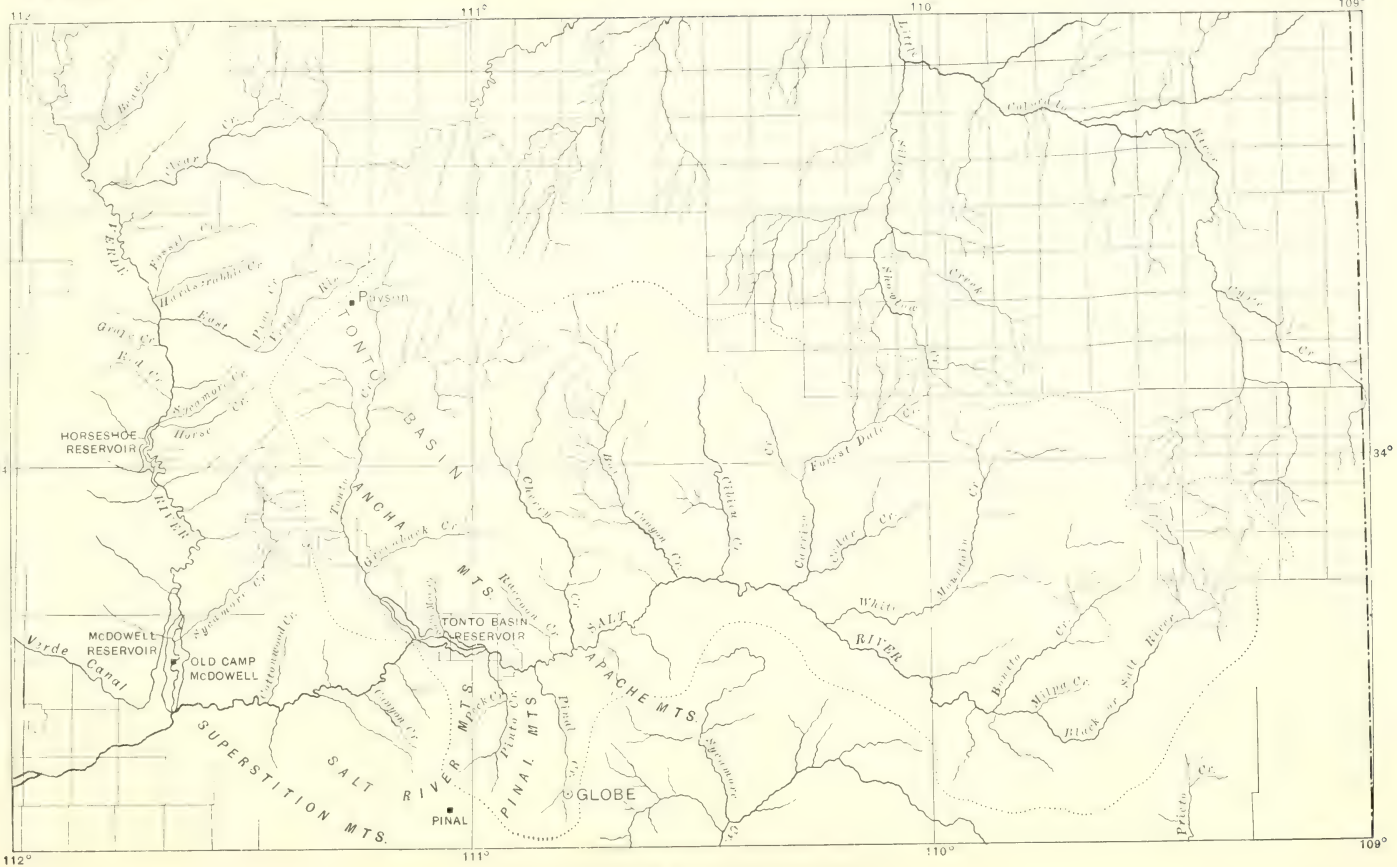
DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 12, 1902.

SIR: I have the honor to transmit herewith a manuscript by Mr. Arthur P. Davis, giving the results of surveys and investigations for water storage on Salt and Verde rivers, Arizona, and request that it be published in the series of Water-Supply and Irrigation Papers.

The results described in this report were obtained by Mr. Davis mainly during the year 1901. Assistance was rendered by the local authorities, committees, and citizens of Maricopa County, Ariz., and through the cooperation thus had it was possible to go into details which under other circumstances could not have been discussed. The work is of great value, not only to the Salt River Valley, but to other portions of the arid region where water storage will in the future be undertaken, as the careful work of Mr. Davis has demonstrated the feasibility of utilizing natural resources, particularly in the making of cement and turning to advantage previously unsuspected means for conserving water. Throughout Arizona and the entire Southwest the development of agriculture, and to a less extent of mining and other industries, rests upon water conservation, since in these vast areas the streams are for the most part of small volume and are subject to occasional destructive floods. The impounding of these is one of the most important fundamental steps to be taken toward the utilization of the vast area of vacant public land.

Very respectfully, F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



DRAINAGE LINES OF SALT RIVER BASIN.

WATER STORAGE ON SALT RIVER, ARIZONA.

By Arthur P. Davis.

INTRODUCTION.

Salt River Valley lies south of the center of the Territory of Arizona, and contains by far the largest irrigated area in that Territory. Its water supply is obtained from Salt River, forming below the confluence of Verde River the largest stream in Arizona.

Verde River drains the central portion of Arizona, and Upper Salt River the east central portion. Both streams are more or less torrential in character, the combined flow dwindling at times to about 100 cubic feet per second, and at other times reaching a volume more than one hundred times as great.

The development of Salt River Valley has been carried on by diverting the natural flow of the river, which is not sufficient for the adjacent lands. Settlement and cultivation, encouraged by years of large or normal water supply, have reached a point where dryer years do not furnish sufficient water for the proper irrigation of lands already in cultivation, and unless the water supply can in some way be increased not only must agricultural development entirely cease, but some of the land already in cultivation must be abandoned.

The unprecedented drought of the last three years has brought the people of this region to a most vivid realization of this condition, and to a strong determination to by some means secure the construction of reservoirs for the storage of the waters which now go to waste during the melting of the snows in the spring, and during the torrential rains of the late summer. The agitation for storage led to the formation of the citizens' committee in Phoenix for promoting investigations and for developing some project for the storage of water. The action taken is set forth in the following communication received in November, 1900, by the Secretary of the Interior, from Mr. B. A. Fowler, president of the Salt River Valley water-storage committee:

The citizens of the Salt River Valley of Arizona have, as a result of a protracted drought, become thoroughly aroused to the vital importance of forest protection, and especially of water conservation through the construction of reservoirs. Mass meetings have been held and an organization formed representing all of the diverse interests of the valley. As president of this organization, I have been instructed and empowered to take active steps toward bringing about better conditions.

A careful study of the situation has shown that, as preliminary to the construction of systems of water storage, we must have a full knowledge of all of the physical conditions of topography, water flow, depth of bed rock, amount of sediment carried by the water, and other facts. With these fundamental facts, and with estimates of the capacity and cost of construction, it will be possible to discuss alternative projects, and to lay before the people the data by which they can be guided in future action, and by which Congress may consider the advisability of public works for the regulation of the streams and for the reclamation of arid lands.

We understand that one of the bureaus of the Department of the Interior, viz, the United States Geological Survey, has been authorized by Congress to ascertain these facts relating to the reclamation of the arid region, the storage of water, and related subjects. Also that the demand for work of this kind far exceeds the funds available for carrying it on, and that as a consequence work is being concentrated in localities where the greatest public interests are to be served, and particularly where cooperation is offered by the people or their legislatures.

In view of these conditions, I am authorized to bring before you the great importance of this work to the people of Arizona, and as an evidence of our earnestness in the matter to offer to cooperate to the extent of furnishing $1,500, to be disbursed upon the usual approved vouchers, an equal amount to be allotted from the funds of the United States Geological Survey, to be expended by the latter in making these investigations. My conference with the officials of the Geological Survey has shown that this proposition is acceptable to them, being similar to the cooperation now in force with the Water and Forest Association of California, and also with officials in various States.

I trust that this matter will meet your hearty approval and this greatly needed investigation can be begun at once.

This letter was referred to the Director of the Geological Survey, who replied to the Secretary of the Interior on January 14, 1901, as follows:

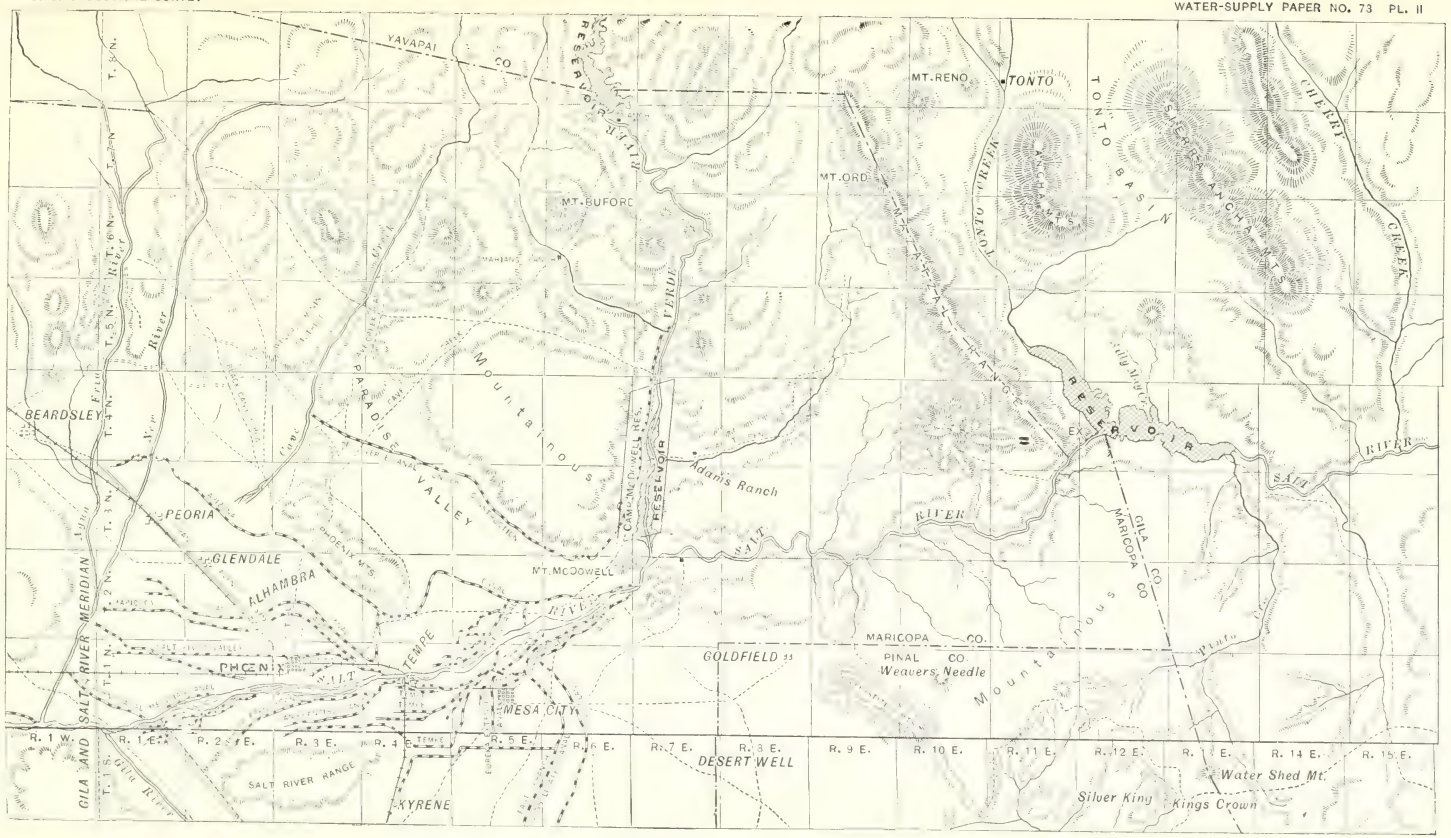
I have the honor to acknowledge, by reference from the Department of December 31, for early report and return of the papers, a letter dated November 20, from Mr. B. A. Fowler, president of the Salt River Valley storage committee.

In this Mr. Fowler offers to cooperate to the extent of furnishing $1,500 in the investigation of the water resources of the portion of country above the Salt River Valley. This offer of cooperation should, in my opinion, be met with hearty approval and investigations pushed forward energetically in those regions where the people testify to the need of this work by furnishing financial aid.

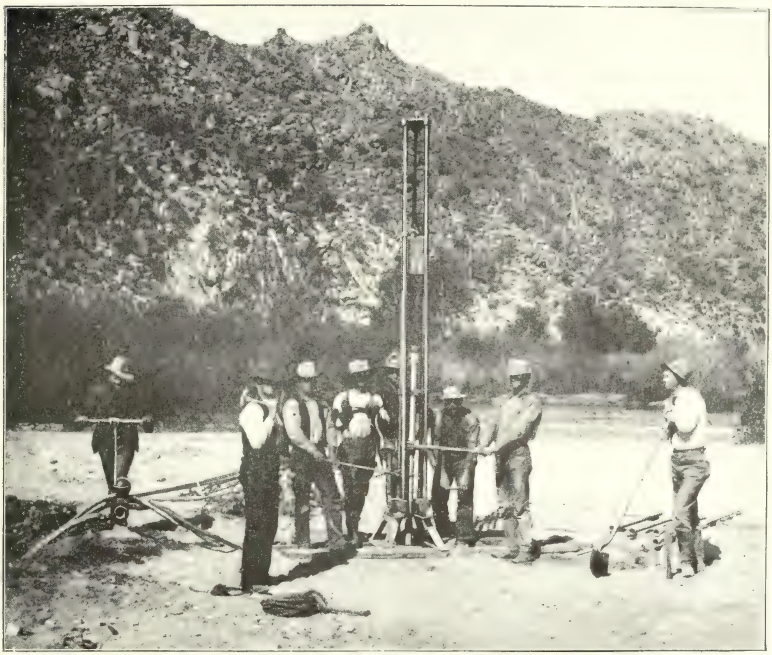
The offer of the Arizona people is comparable to that of the California Water and Forestry Association, which has paid one-half of the field expenses of similar investigations in California during the past year.

Mr. Fowler, after presenting his letter of November 20 to you, and having a personal conversation, filed in this office a copy of the letter. In view of the necessity of beginning work immediately, while the climatic conditions are favorable, I authorized the beginning of this Arizona work, and will have it pushed forward to completion if it continues to meet your approbation, as I understand informally that it does.

The work now in hand consists of a thorough examination of the drainage basin of Verde River, the gaging of the streams, and the determining of the water supply; this latter involving the survey and examination of possible reservoir sites. After this is completed, it is possible that work will be continued on the Salt River above the Verde.



MAP OF SALT RIVER BASIN, SHOWING RESERVOIR SITES.



A DRILL PARTY ON VERDE RIVER; "PIERCE RIG"

B DRILL PARTY ON VERDE RIVER; DIAMOND DRILL.

Accordingly, early in January the investigation of the McDowell reservoir site, near the mouth of Verde River, was begun. Measurements of the flow of the river were also begun at once, and borings were made in order to ascertain the nature of the foundation for the proposed dam. While the borings were in progress surveys were carried on to determine the capacity of the reservoir and the cubical contents of the dam. The work at the McDowell dam site was concluded on April 20, when the public funds available for the work were almost exhausted. About this time the water-storage commission was appointed, under the act of the Arizona legislature, as follows:

No. 65.

AN ACT to authorize any county in the Territory of Arizona having an assessed valuation of eight million dollars or over to prepare plans and specifications for a storage reservoir or reservoirs, dam or dams, to acquire the site for the same, and to provide the necessary funds to defray the expenses incurred.

Be it enacted by the legislative assembly of the Territory of Arizona:

SECTION 1. Any county in the Territory of Arizona having an assessed valuation of eight million dollars or over may avail itself of the benefits of this act by complying with the provisions as hereinafter provided. The board of supervisors, upon the petition of fifty qualified electors and freeholders of said county, shall request the district judge in which the county is located to appoint a board of water-storage commissioners, and the judge shall within ten days thereafter appoint five qualified electors, who shall be resident freeholders of said county, who shall be known and designated as the board of water-storage commissioners. Each of said commissioners shall hold office for one year and until his successor is appointed and qualified. Before entering upon the duties of his office he shall give bond in the sum of one thousand dollars, payable to the said county, for the faithful performance of his duty. Said bonds shall be approved by and filed with the board of supervisors of said county. At its first meeting the board shall organize by the election of one of its members as president. It shall also elect a secretary, who may or may not be of its number. The compensation for the members of said board shall be five dollars per day for each day actually employed. They shall also be allowed their actual traveling expenses. The salary of the secretary shall be fixed by the board. The board shall establish and maintain an office at the county seat of the said county. It shall be the duty of said water-storage commissioners to examine reservoir sites, cause to be made surveys and soundings, determine the capacity and estimate the cost of construction of said proposed reservoir or reservoirs, dam or dams, determine the extent of the watersheds and rainfall thereon; to collect such other information as shall show the water available for storage use in said county for irrigating purposes; to provide for the accumulation of such other information as may be required therefor, and cause abstracts therefrom to be published in some newspaper published and of general circulation in said county; to employ and fix the compensation of a competent engineer or engineers; to prepare plans, specifications, and estimates for said reservoirs and dams and file a copy of the same with the clerk of the board of supervisors of said county; to employ and fix the compensation of legal counsel in any matters arising under this act, or necessary to authorize the construction of the dams or reservoirs referred to in this act, and to select the most available reservoir site or sites, and to acquire the same, together with any rights of way necessary over public or private property, by purchase or through eminent domain, in the name of said county of Maricopa, and for the benefit of the people of said

county; and to negotiate with and obtain agreements from canal companies in relation to the distribution of water or its delivery to the point of ultimate use, and to cooperate with or contribute towards the expenses of any investigations now being made or hereafter to be made by the United States Geological Survey, and to transfer to the National Government any reservoir site or rights therein or thereto, or connected therewith, which may have been acquired hereunder, in the event that the National Government should undertake the construction of the reservoir.

SEC. 2. For the purpose of defraying the expenses of the board of water-storage commissioners, the board of supervisors of any county availing itself of this act shall at the time of levying Territorial and county taxes in the years 1901 and 1902 levy an additional tax of one and one-half mills on the dollar on all taxable property within the said county, to be collected as other taxes are collected; and the same shall be denominated and known as a water-storage fund. The board of water-storage commissioners shall audit and approve all bills for expenses incurred under the provisions of this act, and present the same, together with the claims for their salaries and expenses, to the board of supervisors, who shall, if found correct, pay the same out of any money in the water-storage fund.

SEC. 3. All acts and parts of acts in conflict with the provisions of this act are hereby repealed.

SEC. 4. This act shall take effect and be in force from and after its passage.

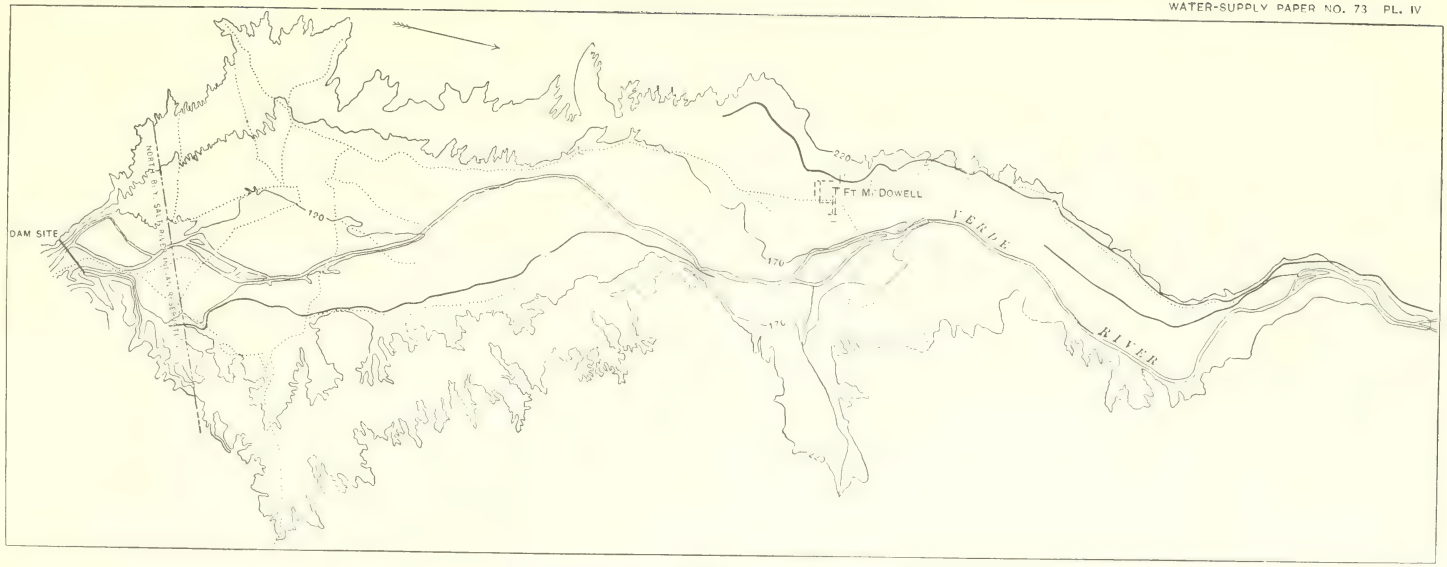
Approved, March 20, 1901.

The water-storage commission consisted of J. T. Priest, Charles Goldman, W. D. Fulwiler, Dwight B. Heard, and J. G. Peterson. Arrangements were made by which the officers of the Geological Survey were to prosecute investigations at the reservoir site on Salt River at the mouth of Tonto Creek, with the machinery and camp equipment of the Geological Survey, the water-storage commission to furnish subsistence and to pay the laborers and incidental camp expenses. Borings and surveys were carried on for about three months, resulting in a thorough knowledge of the foundation conditions for a high dam, the cubical contents of the same, and the capacity of the reservoir site for each 10 feet of elevation above the river from 10 to 200 feet. The results of all these investigations and the plans founded thereon are given in the following pages.

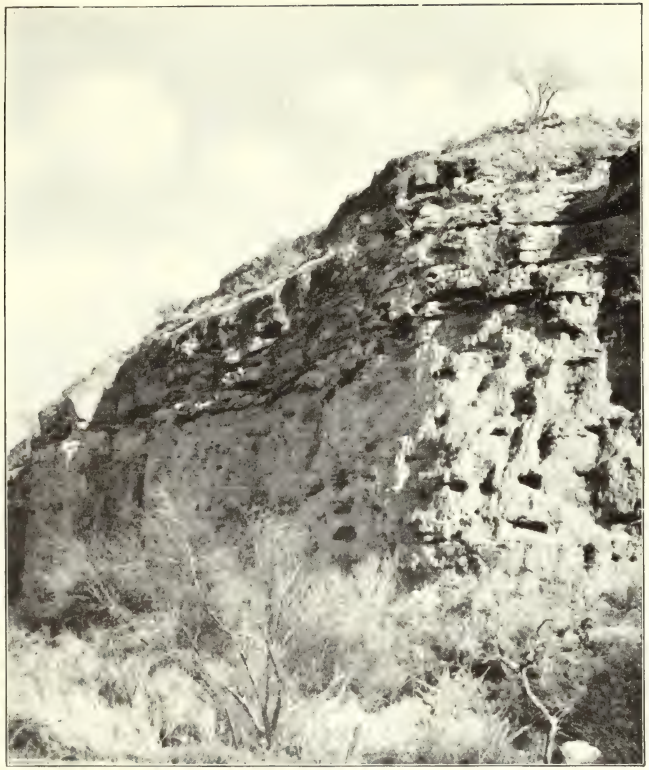
WATER STORAGE ON VERDE RIVER.

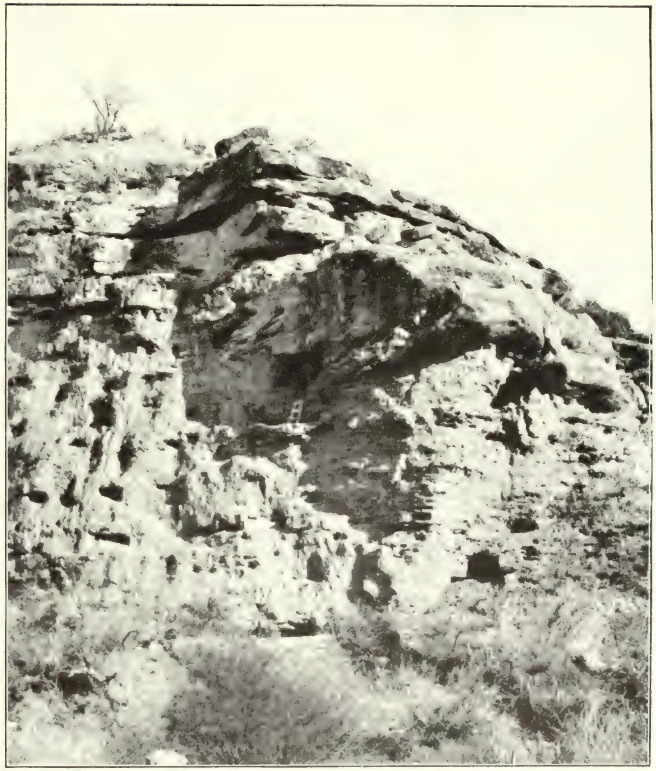
CHARACTER OF DRAINAGE BASIN.

Verde River rises in the Black Forest, near the line of the Atchison, Topeka, and Santa Fe Railway. Its general course is a little east of south, draining the Black Hills and Black Mesa. The principal tributaries from the east are Dragoon Fork, Oak Creek, Beaver Creek, Clear Creek, and East Verde River. All are of considerable length and come from mountainous country, with relatively high rainfall, and furnish the main portion of its waters. The only tributaries of consequence from the west are Walnut Creek, near the head, and Granite Creek, which rises near Prescott and flows northward. These creeks are usually dry. The total area drained by the Verde is about 6,000 square miles, ranging in altitude from 1,250 feet at Camp McDowell to over 8,000 feet. The topography of the basin is widely varied in character.



OUTLINE OF McDOWELL RESERVOIR SITE.





CONGLOMERATE CLIFF McDOWELL RESERVOIR SITE, SHOWING WIND EROSION.

Near the headwaters are Big Chino, Williamson, Little Chino, and Lonesome valleys, each of which is an extensive plain yielding little run-off to the river. The greater portion of the basin, however, is of a mountainous character, being cut with profound canyons and dotted by rugged mountains. Only a small proportion is wooded and the soil is kept nearly bare by excessive grazing. As might be expected, the run-off is largely torrential in character, and the floods carry some silt. In this respect it is not as favorable for storage as the basin of the Salt.

WATER SUPPLY.

The flow of Verde River at Mount McDowell was directly observed by the Hudson Reservoir Company from February 4, 1895, to July 31, 1896; and by the Geological Survey from April 20, 1897, to November 30, 1899, and during 1901. The balance of the record from August 1, 1888, to January 1, 1901, is derived from the record of the discharge of Salt River at Arizona dam below the mouth of the Verde, according to principles set forth on page 24. As these records are necessary in connection with the study of the duty of Salt River reservoir they are given by months in connection therewith, on page 26.

The monthly discharges, as far as completely known, are as follows:

Estimated monthly discharge of Verde River at McDowell.

[Drainage area 6,000 square miles.]

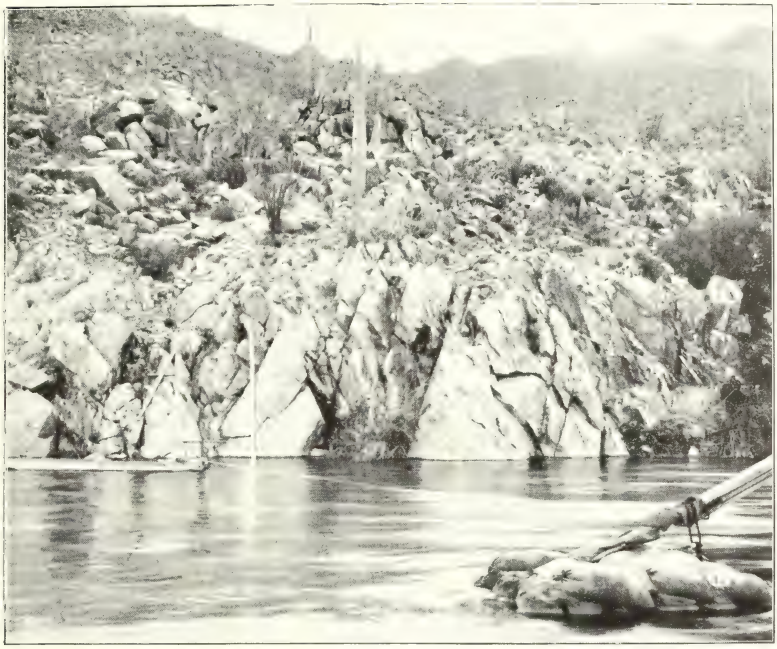
Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1888.[a]						
August	.....	.....	172	10,547	0.03	0.03
September	.....	.....	168	9,996	.03	.03
October	175	150	166	10,178	.03	.03
November	2,880	213	421	25,050	.07	.078
December	21,745	823	3,349	205,964	.56	.645
The year	.....	.....	.....	261,735	.....	.....
1889.[a]						
January	10,480	699	2,498	153,611	.42	.48
February	1,773	690	1,172	65,059	.20	.21
March	13,180	1,390	3,411	209,749	.57	.65
April	1,112	499	795	47,302	.09	.10
May	639	118	197	12,141	.03	.03
June	185	107	141	8,390	.02	.02
July	551	140	208	12,819	.04	.04
August	370	191	204	12,556	.03	.03
September	562	187	250	14,880	.04	.04
October	352	160	220	13,530	.04	.05
November	315	266	288	17,136	.04	.04
December	12,686	279	2,843	174,845	.67	.77
The year	13,180	107	1,018	742,028	.18	2.43
1890.[a]						
January	6,615	578	2,092	128,685	.35	.40
February	64,480	470	4,544	252,172	.76	.79
March	6,719	1,001	2,504	153,967	.62	.71
April	415	274	368	21,896	.06	.07
May	260	120	174	10,680	.03	.03
June	202	119	153	9,121	.03	.03
July	366	167	220	13,535	.04	.04
August	3,760	546	1,904	117,074	.32	.37

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.

Estimated monthly discharge of Verde River at McDowell.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1890.[a]						
September	1,769	348	1,123	66,802	.19	.21
October	3,733	377	1,384	80,116	.02	.02
November	15,252	383	2,359	140,331	.39	.43
December	15,183	555	3,130	192,464	.52	.59
The year	64,480	119	1,666	1,186,843	.278	3.69
1891.[a]						
January	7,193	445	1,435	88,244	.22	.25
February	135,000	371	17,467	970,051	2.91	3.03
March	3,460	525	1,928	118,535	.32	.37
April	606	459	534	31,775	.09	.10
May	361	365	458	28,190	.08	.09
June	539	280	401	23,849	.07	.08
July	405	252	314	19,291	.05	.06
August	368	251	278	17,113	.05	.06
September	631	229	395	23,478	.06	.07
October	310	231	258	15,833	.04	.04
November	314	231	256	15,233	.04	.04
December	346	294	328	20,168	.05	.06
The year	135,000	229	2,004	1,371,760	.332	4.25
1892.[a]						
January	360	257	284	17,458	.05	.06
February				[b]11,046		
March				[b]9,832		
April				[b]5,213		
May				[b]5,608		
June				[b]3,106		
July	215	136	152	9,374	.02	.02
August	276	162	198	12,172	.03	.03
September	188	157	164	9,768	.03	.03
October	875	164	223	13,712	.04	.04
November	435	225	257	15,263	.04	.04
December	296	263	282	17,309	.05	.06
The year				129,861		
1893.[a]						
January	231	231	231	14,204	.04	.04
February	4,781	248	672	37,313	.11	.11
March	144,306	230	5,386	331,168	.90	.04
April	495	141	290	17,244	.05	.06
May	380	64	150	9,253	.02	.02
June	106	44	68	4,052	.01	.01
July	478	117	225	13,842	.04	.04
August	1,240	233	802	49,321	.13	.15
September	1,164	284	530	31,532	.09	.10
October	244	276	376	23,120	.06	.07
November	339	280	296	17,613	.05	.06
December	325	313	315	19,338	.05	.06
The year	144,306	44	778	568,000	.13	1.76
1894.[c]						
January	264	231	244	15,030	.04	.04
February	284	236	259	14,395	.04	.04
March	996	205	530	32,565	.09	.10
April	269	95	171	10,187	.02	.02
May	89	60	68	4,159	.01	.01
June	133	66	79	4,713	.01	.01
July	223	66	119	7,334	.02	.02
August	923	140	439	26,996	.07	.08
September	715	139	292	17,365	.05	.06
October	714	122	242	14,880	.04	.04
November	303	207	230	13,656	.04	.04
December	820	233	442	27,147	.07	.08
The year	923	60	259	188,427	.04	.54

[a] Obtained by taking proportional part of discharge of Salt River at Arizona dam.
[b] Approximate, from minimum discharge recorded for same months in 1900.
[c] Obtained by taking proportional part of discharge of Salt River at Arizona dam. Using Mr. Trott's computations.



A. WEST ABUTMENT OF McDOWELL DAM SITE, SHOWING GAGE ROD.

B. EAST ABUTMENT OF McDOWELL DAM SITE.

Estimated monthly discharge of Verde River at McDowell—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1895.[a]						
January	33,000	527	4,037	248,225	.67	.77
February	5,800	583	1,688	93,747	.28	.29
March	8,400	1,887	3,720	228,734	.62	.71
April	2,800	280	750	44,628	.13	.14
May	429	127	258	15,864	.04	.04
June	180	129	153	9,104	.03	.03
July	275	116	145	8,916	.02	.02
August	1,426	185	359	22,054	.06	.07
September	348	141	176	10,473	.03	.03
October	3,912	197	475	29,207	.08	.09
November	1,800	241	463	27,550	.08	.09
December	881	345	391	24,042	.07	.08
The year	33,000	116	1,051	762,564	.18	2.36
1896.						
January	354	314	324	19,923	.05	.06
February	352	278	154	8,852	.03	.03
March	338	258	276	16,971	.05	.06
April	237	206	220	13,090	.04	.04
May	206	138	172	10,576	.03	.03
June	137	101	117	6,962	.02	.02
July	3,380	98	864	53,127	.14	.16
August[b]	5,323	272	849	52,213	.18	.21
September[b]	4,466	252	557	33,132	.06	.07
October[b]	630	301	452	27,823	.05	.06
November[b]	747	334	492	29,306	.05	.06
December[b]	444	326	352	21,644	.04	.05
The year[b]	5,323	98	402	293,629	.06	.85
1897.						
January[b]	15,687	252	2,138	131,474	.36	.41
February[b]	2,245	487	873	48,484	.15	.16
March[b]	4,013	706	1,504	92,492	.25	.29
April[b]	2,706	316	1,189	70,774	.20	.23
May	460	170	269	16,540	.045	.052
June	185	120	150	8,920	.025	.028
July	230	90	130	7,993	.022	.025
August	1,590	110	439	26,993	.073	.084
September	5,000	240	992	59,028	.165	.184
October	390	260	309	19,000	.051	.059
November	265	260	262	15,590	.044	.049
December	280	260	267	16,417	.045	.052
The year	15,687	90	710	513,705	.12	1.61
1898.						
January	1,680	120	253	15,556	.04	.04
February	800	290	496	27,546	.08	.09
March	1,535	210	639	39,291	.11	.13
April	710	180	319	18,982	.05	.06
May	280	130	184	11,314	.03	.03
June	160	130	139	8,271	.02	.02
July	1,890	115	323	19,861	.05	.06
August	1,730	165	400	24,595	.07	.08
September	1,380	165	338	20,112	.06	.07
October	180	160	169	10,391	.03	.03
November	230	165	195	11,603	.03	.03
December	440	220	303	18,631	.05	.06
The year	1,890	115	313	226,153	.05	.70
1899.						
January	560	295	350	21,521	.06	.07
February	375	295	344	19,105	.06	.06
March	325	225	260	15,987	.04	.05
April	230	170	205	12,198	.03	.03
May	210	118	152	9,346	.03	.03
June	230	118	152	9,045	.03	.03
July	1,400	118	365	22,443	.06	.07
August	2,170	100	434	26,686	.07	.08
September	2,500	135	357	21,243	.06	.07
October	3,770	160	549	33,757	.09	.10
November	250	235	203	13,240	.03	.03
December	364	223	292	13,343	.05	.06
The year	3,770	100	305	217,914	.05	.68

[a] Obtained by taking proportional part of discharge of Salt River at Arizona dam. Using Mr. Trott's computations.

[b] Computations made from Mr. Trott's figures.

Estimated monthly discharge of Verde River at McDowell—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.[a]						
January	195	179	189	11,621	.03	.03
February	211	184	199	11,046	.03	.03
March	187	144	160	9,832	.03	.03
April	125	74	88	5,213	.01	.01
May	190	46	91	5,608	.02	.02
June	75	36	52	3,106	.01	.01
July	105	36	52	3,176	.01	.01
August	555	68	151	9,235	.02	.02
September	305	92	121	7,198	.02	.02
October	408	107	183	11,252	.03	.03
November	2,469	163	430	25,617	.07	.08
December	272	205	224	13,775	.04	.04
The year	2,469	36	161	116,679	.025	.33
1901.[b]						
January	1,557	259	351	21,575	.06	.07
February	6,613	394	1,859	103,249	.30	.31
March	2,863	211	895	55,018	.15	.17
April	221	155	184	10,988	.03	.03
May	185	125	139	8,606	.02	.02
June	164	59	104	6,222	.02	.02
July	1,430	29	210	12,916	.04	.04
August	1,755	163	627	38,561	.11	.13
September	172	45	93	5,514	.01	.01
October	495	82	134	8,210	.02	.02
November	336	187	245	14,571	.04	.04
December	291	247	268	16,485	.04	.04
The year	6,613	29	426	301,915	.07	.90
1902.						
January	262	197	224	13,785	.03	.03
February	248	227	239	13,277	.04	.04

[a] No observations made during 1900 by United States Geological Survey. Computations made from Mr. Trott's figures.
[b] Computations made from observations taken by United States Geological Survey.

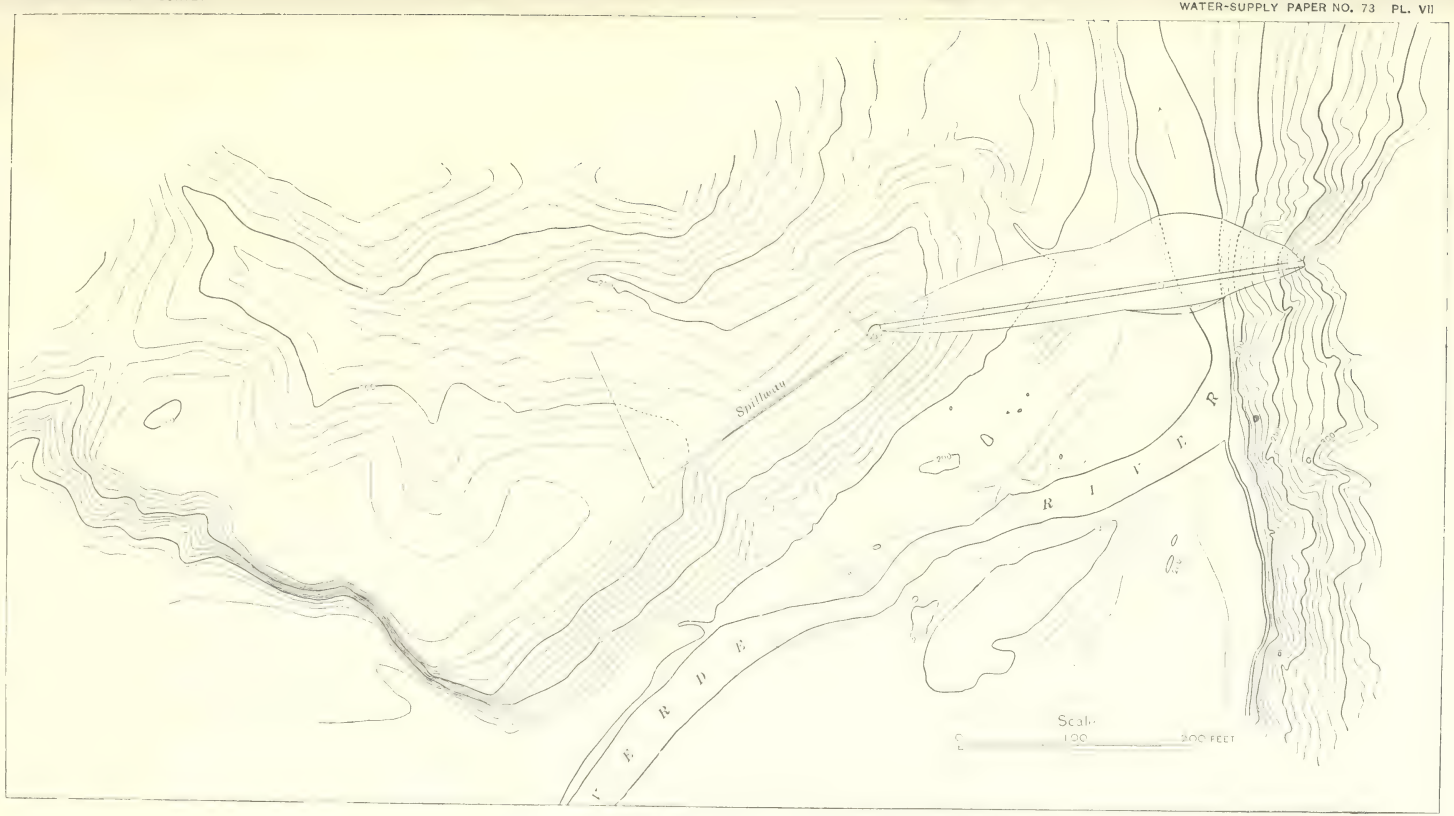
Two storage reservoirs have been proposed upon Verde River. The Horseshoe reservoir, which is described in Water-Supply and Irrigation Paper No. 2, page 62, is situated about 30 miles above old Camp McDowell, near the mouth of Limestone Creek. An outlet tunnel has been cut and a portion of the canal has been built, but work has been suspended for several years. The capacity of this reservoir would be about 200,000 acre-feet.

McDOWELL RESERVOIR.

This reservoir site is situated above Mount McDowell, near the mouth of the Verde, and includes the site of old Camp McDowell. The dam site is about 2 miles above the mouth of the Verde. This reservoir site was suggested and partly surveyed by Mr. Frank P. Trott, the water commissioner of Salt River Valley.

BORINGS.

Early in January, 1901, field work was begun by the Geological Survey, and an examination of the McDowell reservoir site on Verde River was made. Two pipe-driving machines and a diamond drill were taken to the ground, and borings were begun to determine the position and character of bed rock at the site of the proposed dam, Mr. W. E. Jones, of Des Moines, Iowa, being employed as drill foreman



PLAN OF McDOWELL DAM.

Mr. C. R. Olberg was intrusted with the construction of a map of the reservoir site in 10-foot contours, on a scale of 1,000 feet to an inch, and a detailed map of the dam site was made on a scale of 100 feet to an inch. The field work was under the general direction of Mr. F. P. Trott, whose duties as water commissioner, however, prevented his continued presence on the ground, so that the immediate charge was assigned to Mr. E. G. Hamilton.

The borings began by attempting a straight row of holes along the axis of the dam proposed by Mr. Trott. The conditions were found to be very difficult. At a depth of about 30 feet a bed of very hard cemented gravel was encountered, into which it was impossible to drive the pipe, except with the assistance of blasting, but which was not sufficiently coherent to be classed as solid rock.

The work was also hampered by the fluctuation of the river, the floods threatening several times to wreck or sweep away the machinery.

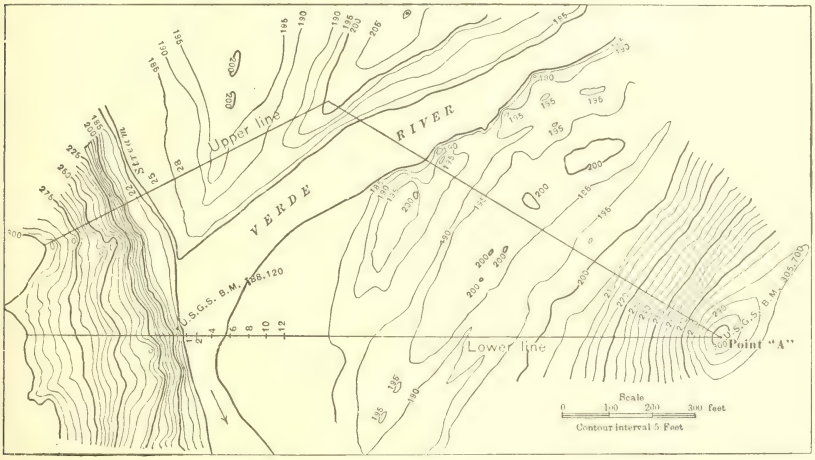


FIG. 1.—Plan of borings at McDowell dam site.

By February 26 it had been demonstrated that it was at least more than 70 feet to bed rock in hole No. 6 on the main axis of the proposed dam, and the work being hampered here by fluctuating water, Mr. Trott determined to try along an alternate location, shown in fig. 1, farther upstream, and both machines were set to work there on holes Nos. 21 and 25. The former was soon completed, showing a depth to rock of 21 feet. The machine was removed to the site of No. 28. Work was pushed on 25 and 28 until the former reached a depth of 90 feet without striking rock. This was considered a prohibitory depth for this location and the machinery was returned to the first location to continue the exploration of the main line. This was completed on April 20.

The location of the borings on both lines is shown in fig. 1. The depths of borings are shown in the table following.

Borings at McDowell dam site.

Hole number.	Distance from bench mark.	Depth to bed rock.	Total depth.	Character of bed rock.
	Feet.	*Feet.*	*Feet.*	
1	20	22	22	Granite.
2	40	35	38	Rotten granite.
4	80	90	99	Broken granite.
6	120	80	92	Do.
8	160	49	59	Granite.
10	200	40	46	Hard gray granite.
12	240	52	65	Broken granite.
21	.....	22	26	Granite.
25	.....	.....	90	No bed rock reached.
28	.....	.....	50	Do.

CAPACITY.

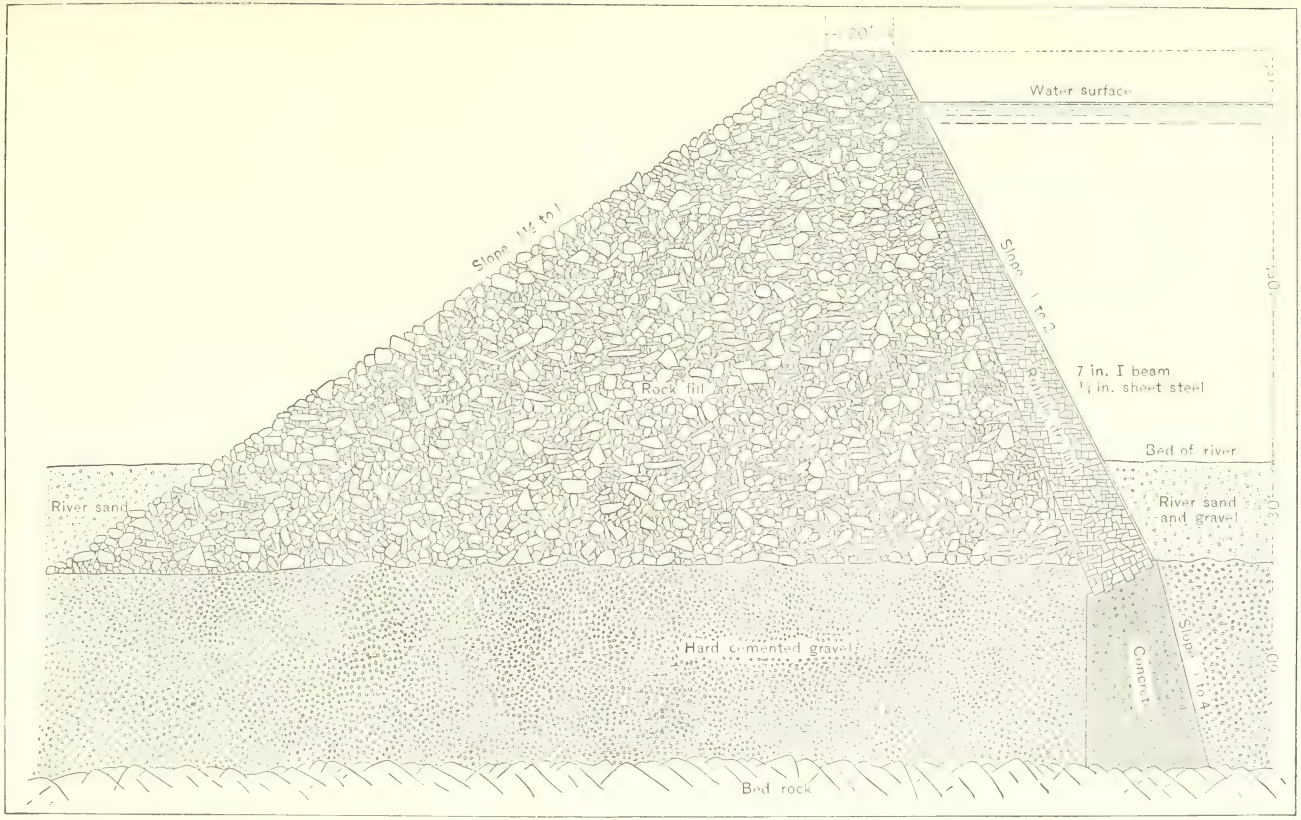
Capacity of McDowell reservoir.

Elevation above lowest foundation.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
100	14	70	70
110	91	525	595
120	331	2,110	2,705
130	717	5,240	7,945
140	1,073	8,950	16,895
150	1,661	13,670	30,565
160	2,292	19,765	50,330
170	3,134	27,130	77,460
180	4,034	35,840	113,300
190	4,990	45,120	158,420
200	6,020	55,050	213,470
210	7,213	66,165	279,635
220	8,493	.....	.....

PLANS FOR THE DAM.

The map of the reservoir site was made on a scale of 1,000 feet to an inch, with a contour interval of 10 feet. A reduced outline of it is given in Pl. IV. The map of the dam site was made on a scale of 100 feet to an inch, with a contour interval of 5 feet. A reduction is shown in Pl. VII.

The capacity of the reservoir is very large, so far as it goes, but the practicable height of dam is limited by the height of the east abutment. The total excavation to bed rock is large, and much of the material to be excavated is hard. At a depth of 30 feet, more or less, the river gravel is underlain down to bed rock by a very hard cemented mixture of sand and gravel, which would be very expensive to excavate in case a masonry dam was constructed, but is sufficiently firm to serve as foundation for a rock-fill structure. The cost of a masonry dam would be prohibitory. The moderate height, the great length, and the abundance and convenience of suitable rock are all additional arguments in favor of the rock-fill type, and it is without doubt the most suitable. The most unfavorable feature of the whole project is



CROSS SECTION OF McDOWELL DAM

the character of the east abutment at the dam site. The granite bed rock appears on the surface on the east side of the river, but seems to enter the hill on a nearly horizontal grade. The hill above the granite, which constitutes the upper 90 feet of the abutment, is composed of an indurated mixture of coarse sand and gravel of the same character as the foundation described above, too hard to excavate with a pick, but not to be classified as rock, and inclined to disintegrate upon exposure to the air. It is probable that under high head, water might percolate through this material to some extent, at least where the abutment is thinnest; and to insure against this a concrete core is to be carried into the hill a distance of about 300 yards, where the hill becomes over 1,000 feet thick. Supposing this core to be 6 feet in thickness, the excavation and masonry would cost about $600 per running yard, and hence would add $180,000 to the cost of the construction. The bond between the concrete core and the adjacent natural deposit should be made as thorough as possible by filling the joint with Portland cement concrete, well rammed in place, so that there can be no creeping of water along the wall. With proper precautions it is believed that a dam of the proposed height, 120 feet, could be safely built and maintained.

At the site of the dam the river bed is composed of ordinary sand and gravel to a depth of about 30 feet, when the compact cemented gravel is encountered. The depth to bed rock is about 90 feet at the deepest point. It is proposed to carry a concrete wall down to bed rock across the canyon, at the upstream toe of the dam. This wall will be 35 feet thick at the base on bed rock and diminish to 15 feet at the top. Downstream from this wall the river sand and gravel will be excavated down to the cemented material above mentioned, and upon this will be founded the main dam, which is to be of the rock-fill type, the upstream face to be on a slope of 1 in 2, and the downstream slope 3 in 2, with a top width of 20 feet. The rock will be obtained from the mountain of granite that rises abruptly from the west abutment. The rock can be transported down grade on a cable way, and dropped on the dam in large blocks, from a considerable height, which will serve to ram it solidly in place, and it is believed very little settlement will occur. On the upstream face is to be a wall of rubble masonry resting on the concrete wall that goes down to bed rock. The masonry will have a thickness of 20 feet at the bottom, diminishing to 5 feet at the top. Against its downstream side will be built the mass of dry rock fill; on the water face, which will have a slope of 1 in 2, will be placed, at intervals of 20 feet, a series of 7-inch steel **I**-beams, each extending from the bottom to the top of the dam. To these beams will be fastened a floor of one-fourth inch steel plates, dipped in asphalt and riveted together to form a water-tight skin over the entire water slope of the dam. The space between the steel plates and the masonry will be filled with concrete tightly rammed. The

concrete and rubble walls will unite at the ends with the concrete core, which is to be carried into the east abutment, as above described.

The outlet will be through a tunnel of concrete built through the dam along the bed of the river, provided with Stoney gates, similar in construction and mechanism to those for the Salt River reservoir, illustrated in Pl. XXII. All water will be drawn from the bottom of the reservoir, and whenever the spillway begins to discharge, the gates will be opened to full capacity for the purpose of discharging the maximum quantity of silt and of reenforcing the spillway.

For diverting the river during construction a temporary diversion dam could be placed across the river about 4,000 feet above the dam site, and the water diverted into a large flume and carried along the east side of the river over the portion of the foundation where granite bed rock appears on the surface. The underflow can probably be sufficiently checked by driving sheet piling down to the bed of indurated gravel, with which the valley is underlain at a depth of about 30 feet. After the dam becomes too high to use this flume the discharge will be through the outlet tunnel. The flume should be removed early in the spring, at the beginning of the low-water season, and construction pushed rapidly, so as to have a large storage and discharge capacity ready for the first flood.

SPILLWAY PROVISIONS.

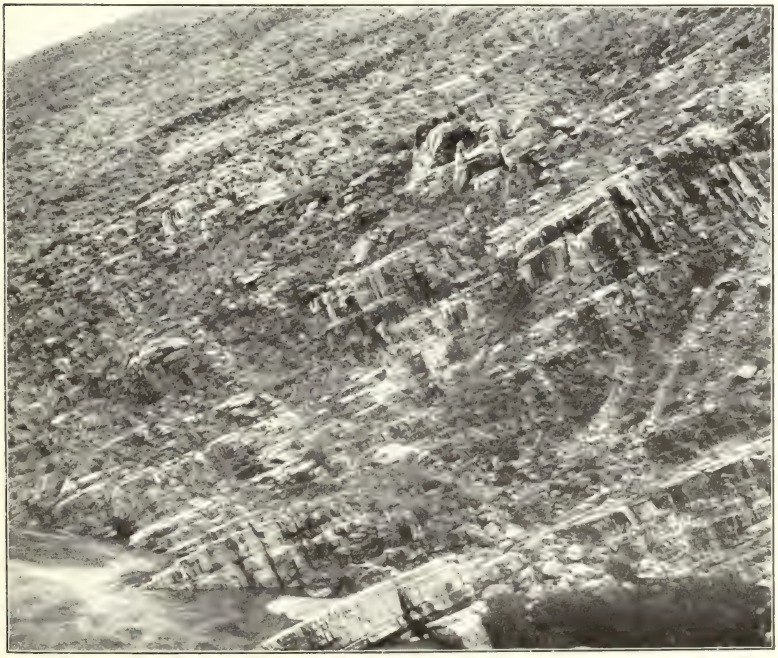
The greatest flood that ever occurred in Salt River Valley since its settlement occurred in February, 1891. It is described in the Twelfth Annual Report[a] of the Geological Survey, as follows:

> On February 17 the mean discharge was 835 second-feet, increasing the next day to 154,000 second-feet, and on the 19th to 276,000. This first flood diminished rapidly, averaging on the 20th only 69,100, and on the 22d 14,890. This was followed by a second swell greater than the first, the flood increasing until, on the 24th, a maximum of 300,000 second-feet was reached. This subsided almost as rapidly as it came, so that by the second day after the river was carrying less than 15,000 second-feet.

The drainage area from which this flood was drawn was considerably more than double that above the McDowell reservoir. A smaller drainage basin is, however, liable to a relatively higher flood discharge than a larger one, though the floods are of shorter duration. It is therefore estimated that the basin under consideration may discharge a flood having a maximum volume of 200,000 cubic feet per second, or two-thirds that of 1891 at Phoenix. On the above assumptions a maximum flood has been hypothecated and the behavior of the reservoir under the circumstances investigated. It is assumed that the reservoir is full up to the bottom of the spillway, and that a great flood discharges 100,000 cubic feet per second on an average for one hour, and increases its discharge 10,000 cubic feet per second during

[a] Twelfth Ann. Rept. U. S. Geol. Survey, Part II, p. 313.

A VIEW IN McDOWELL RESERVOIR BASIN.



B CAPE HORN, SALT RIVER CANYON, SHOWING UPSTREAM DIP OF STRATA.

each hour for eleven hours, at the end of which time it has reached its maximum wave of 200,000 cubic feet per second. The discharge then decreases in an arithmetical progression for twenty hours at the rate of 5,000 second-feet per hour, reaching a discharge of 100,000 second-feet as a mean for the thirty-first hour. The spillway, as planned, has a total length of 900 feet, and its bottom is 15 feet below the top of the dam. Its discharge capacity is computed from the formula $Q=H^{\frac{3}{2}}\ 3150$. Assuming that the gates will be opened to their full capacity when the spillway begins to discharge, the effect on the reservoir of the hypothetical flood is shown in the following table:

Effect of maximum flood in McDowell reservoir with spillway 900 feet long.

[$Q=H^{\frac{3}{2}}\ 3150$.]

Hour.	Inflow.		Outflow.		Net rise.	Elevation.
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.		
					Feet.	
1	100,000	8,260	6,289	518	1.29	201.29
2	110,000	9,090	13,147	1,085	1.28	202.57
3	120,000	9,920	22,759	1,879	1.26	203.83
4	130,000	10,740	34,176	2,822	1.21	205.04
5	140,000	11,570	46,688	3,857	1.15	206.19
6	150,000	12,390	59,856	4,944	1.09	207.28
7	160,000	13,220	73,371	6,060	1.03	208.31
8	170,000	14,040	86,996	7,185	.97	209.28
9	180,000	14,870	100,552	8,297	.91	210.19
10	190,000	15,690	113,506	9,375	.86	211.05
11	200,000	16,520	127,058	10,494	.81	211.86
12	195,000	16,110	138,676	11,455	.62	212.48
13	190,000	15,690	147,681	12,197	.46	212.94
14	185,000	15,290	154,392	12,752	.33	213.27
15	180,000	14,870	159,128	13,144	.22	213.47
16	175,000	14,460	161,896	13,372	.14	213.61
17	170,000	14,040	163,721	13,524	.07	213.68
18	165,000	13,630	164,349	13,576	.00	213.68
19	160,000	13,220	164,000	13,546	−.04	213.64
20	155,000	12,800	162,597	13,430	−.08	213.56
21	150,000	12,390	161,764	13,361	−.13	213.43
22	145,000	11,980	158,353	13,080	−.15	213.28
23	140,000	11,570	155,587	12,851	−.17	213.11
24	135,000	11,150	152,500	12,956	−.19	212.92
25	130,000	10,740	149,136	12,319	−.21	212.71
26	125,000	10,330	145,484	12,016	−.22	212.49
27	120,000	9,920	141,640	11,699	−.24	212.25
28	115,000	9,500	137,602	11,365	−.25	212.00
29	110,000	9,090	133,297	11,101	−.26	211.74
30	105,000	8,680	129,105	10,664	−.27	211.47
31	100,000	8,260	124,739	10,303	−.28	211.19
Capacity			187,975	15,526		215.00

COST.

The following estimate is based upon the data at hand and worked up April 12, 1902, and is subject to modification:

Estimate of the cost of the McDowell reservoir, on Verde River, with capacity of 186,000 acre-feet.

745,875 cubic yards rock fill, at 80 cents a yard	$596,700
78,155 cubic yards dry-laid rubble, at $2 a yard	156,310
7,865 feet, or 117,975 pounds, I beams, at 7 cents a pound	8,258
140,680 square feet quarter-inch plates, or 1,434,936 pounds, at 7 cents a pound	100,445

Excavation, 58,667 cubic yards cemented gravel, at $1 a yard	$58,667
Excavation, 125,000 cubic yards sand, at 20 cents a yard	25,000
5,210 cubic yards of concrete, under steel apron, at $10 a yard	52,100
18,792 cubic yards of concrete in toe wall, at $10 a yard	187,920
Diversion of river	10,000
Outlet, gates, tower, etc	20,000
Concrete core wall to be carried into east abutment	180,000
Engineering and contingencies, 15 per cent	209,331
Right of way	20,000
	1,624,731

Cost per acre-foot capacity, $8.74.

WATER STORAGE ON SALT RIVER.

CHARACTER OF DRAINAGE BASIN.

Salt River, though nominally a tributary of the Gila, really brings far more water to their junction than does the Gila. Though it drains a smaller area, its basin is much higher and cooler and receives an average precipitation far beyond that of the Gila Basin.

The drainage basin of Salt River and its divisions is about as follows:

Area of drainage basin of Salt River.

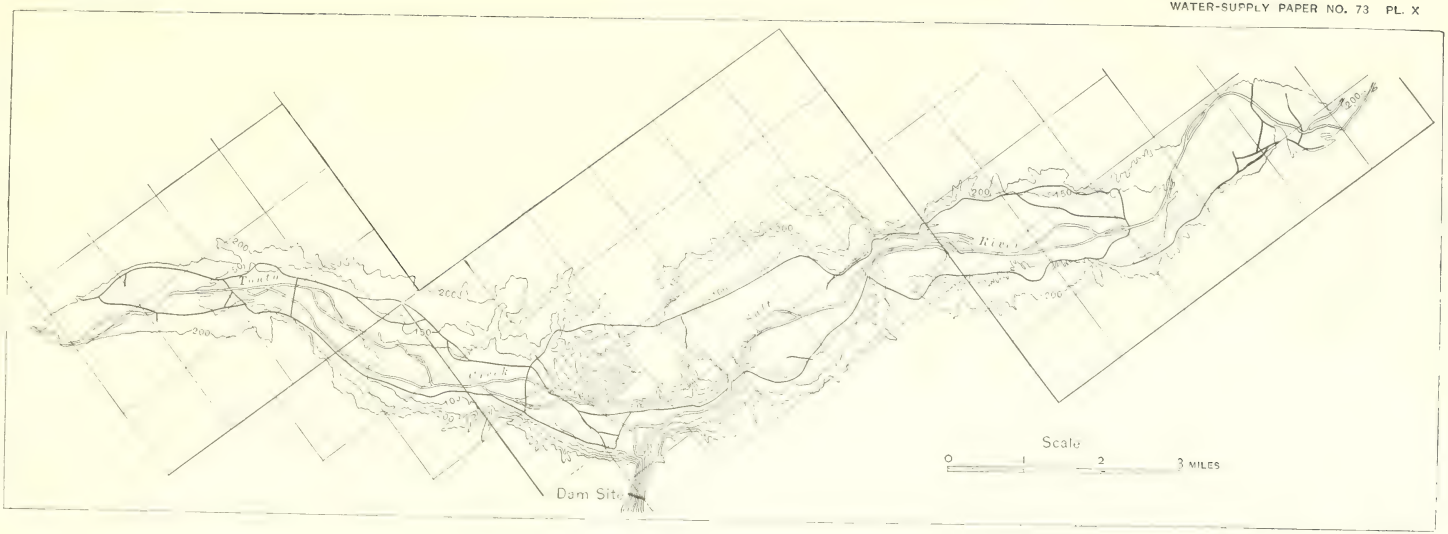
	Square miles.
Salt River at its mouth	12,700
Salt River at Arizona dam	12,260
Verde River near its mouth	6,000
Salt River above mouth of Verde	6,260
Salt River at dam site below Tonto Creek	5,756
Salt River between mouth of Verde and Tonto dam site	504

The elevation at the mouth is about 1,000 feet, while some of the peaks at its headwaters exceed 10,000 feet in altitude, the highest, Thomas Peak, being given as 11,496 feet.

Rather peculiar conditions exist in Salt River Basin, which favor a large water supply relative to its drainage area. In a previous publication the writer has described these conditions, as follows:[a]

The southern portion of the Territory may be again subdivided into two portions, that draining directly into the Colorado and lying to the westward of Prescott, and the greater portion to the south and east, which forms the great Gila River system. The Colorado plateau is partly of igneous origin, and a great portion of it is somewhat pervious to water. Its northern slope for a considerable distance from the summit is very gentle, and though the precipitation is greater than in most portions of the Territory, it is very meagerly marked by drainage lines and almost destitute of water. Sharply contrasted with these facts are the conditions on the southern slope. Here, through most of its course, the plateau drops off with a very steep slope, which is deeply cut with drainage lines in which are living creeks and rivulets of clear, beautiful water, such as San Francisco River, Black Creek, Bonito Creek, White River, Carrizo Creek, Cibicu Creek, Box Creek, Cherry Creek, Tonto Creek, Wild Rye Creek, East Verde River, Pine Creek, Fossil Creek, Clear Creek, Beaver Creek, etc.

[a] Irrigation near Phoenix, Ariz.: Water-Supply and Irrigation Paper, U. S. Geol. Survey, No. 2, p. 15.



OUTLINE OF SALT RIVER RESERVOIR SITE.

The region of high altitude, as before remarked, lies largely north of the divide, while the great bulk of the water flowing from the plateau, as proved both by erosion of drainage lines and by the volume of permanent streams, flows away to the south. The explanation of this is partly the porosity of the strata composing the plateau, which allows the water to sink instead of flowing off the surface. Once underground, its egress to the south is favored by the shorter distance which it must percolate on a given grade before reaching a surface, due to the more abrupt slope.

Another partial explanation is found in the meteorological condition. The moisture of this region is brought from the Pacific Ocean and the Gulf of California by the prevailing southwest wind. As this wind ascends the elevations toward the Colorado Plateau its temperature is lowered, which reduces its capacity for holding moisture and increases its relative humidity. When this quantity reaches 100 per cent in any part, precipitation occurs. This influence continues until the wind passes the summit, where the process is reversed.

As might be expected, therefore, the hydrographic resources of the country immediately southwest of the Colorado Plateau are disproportionately great when compared with those to the northward. For instance, the precipitation at Fort Apache, as shown by a mean of twenty years' observations, is 19.75 inches, the elevation being 5,050 feet, while the precipitation at Holbrook, at an elevation of 5,047 feet, on the northern slope, is 8.47 inches, as indicated by the mean of ten years' observations. This is an important fact, especially when taken in connection with the fact that the great areas of valley land with a semitropic climate lie in the southwestern portion of the Territory, and are easily covered by the streams which are formed by the conditions above described, and which constitute the main features of the great Gila River system.

The topography of the basin of Salt River proper above the mouth of the Verde is nearly all of a rough, mountainous character. The chief tributary above this point is Tonto Creek, and about half a mile below this stream Salt River enters a profound canyon, with precipitous sides and narrow bottom, in which is located the proposed dam site. The Salt and Tonto both occupy comparatively open valleys above this gorge and have a moderate fall. The combined effect is one of the most capacious reservoir sites in the West. The dam might be built to a height of 300 feet or more, if such a height were justified by the water supply.

WATER SUPPLY.

The only available rainfall observations in the basin tributary to the proposed reservoir are those at Payson and Camp Apache. The record at Payson is so short and broken that it is of no real value in the discussion of the water supply, so only that of Camp Apache remains. Fortunately this station is located near the center of the basin, and the record is reliable and complete from 1876 to date—about twenty-six years. This affords excellent means of obtaining monthly and annual maxima, minima, and means at this point, which, so far as known, may be assumed to represent an average of the entire basin as nearly as any one point that might be selected.

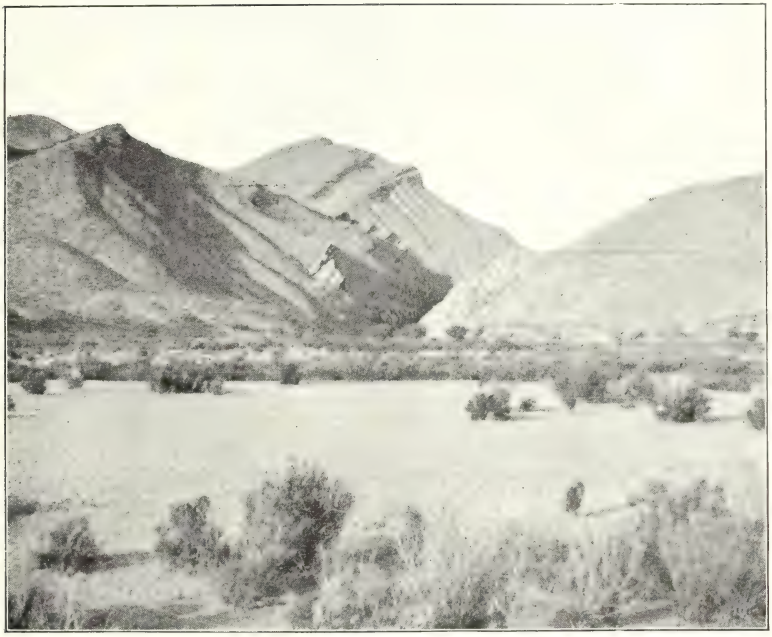
Precipitation, in inches, at Camp Apache.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1876	0.92	1.72	2.02	0.08	0.26	1.02	5.20	2.52	2.00	2.44	1.34	0.22	19.74
1877	.36	.94	.72	.96	1.15	.00	3.11	1.20	.99	.81	.19	2.07	12.50
1878	.18	1.35	2.41	1.77	.18	.79	8.76	9.33	.76	.00	1.94	1.14	28.61
1879	1.89	1.17	.03	.12	.00	.05	3.92	3.06	1.52	2.64	1.77	2.41	18.58
1880	1.31	.95	.80	.46	.00	.46	5.83	1.44	.55	.56	.03	2.38	14.77
1881	.20	1.17	2.45	1.53	.35	T.	5.63	8.31	5.41	4.68	.85	.54	31.12
1882	2.82	2.85	1.09	.91	.94	3.27	4.79	7.36	1.02	T.	2.34	.23	27.62
1883	.85	2.46	2.03	.22	.86	.02	5.46	4.26	.60	1.39	.02	3.48	21.65
1884	.68	3.43	4.44	1.67	1.31	2.35	.14	5.59	1.50	2.02	.82	5.52	29.47
1885	.52	1.00	2.05	.52	1.12	.82	2.60	3.16	.44	.38	1.56	1.41	15.58
1886	3.90	2.73	1.06	.91	.00	.19	1.90	4.75	3.16	1.66	.56	.24	21.06
1887	.59	2.16	.04	.81	.15	1.70	3.29	3.92	2.23	.55	1.83	.57	17.84
1888	1.42	1.83	2.92	.71	.71	T.	3.24	[1.00]	.32	1.23	2.63	2.88	18.89
1889	2.24	.88	1.85	.47	.00	.11	2.67	2.87	1.02	.46	.55	3.98	17.10
1890	2.26	2.40	.82	1.39	.00	.00	5.00	4.44	2.37	2.17	2.85	3.02	26.72
1891	1.65	4.10	.85	T.	.36	T.	2.72	1.22	1.81	.00	.00	.65	13.36
1892	.65	2.29	2.22	1.36	.36	.15	1.33	1.30	1.23	.55	.57	.69	12.76
1893	.28	1.10	2.45	.00	2.18	.00	2.57	3.43	2.65	.04	.28	.10	15.08
1894	1.24	.96	1.36	.19	.79	.00	1.27	5.01	1.32	2.47	.00	2.81	17.42
1895	1.89	.72	.02	T.	1.00	.01	.74	5.44	1.68	3.02	2.39	1.12	18.03
1896	.16	.33	.86	.34	.00	.52	4.31	4.36	1.34	2.42	.77	.68	16.09
1897	2.23	1.40	1.79	.24	.34	.37	1.20	2.07	3.41	1.30	.00	.57	14.92
1898	2.76	1.50	1.08	.50	2.70	2.60	4.33	3.59	.12	.00	.57	.80	20.55
1899	1.33	1.04	.17	.45	.00	1.90	4.55	.96	1.52	.82	.71	1.60	15.05
1900	.30	.29	1.15	1.75	.10	.00	.82	1.31	2.79	.77	4.86	T.	14.14
1901	2.87	2.60	1.20	.20	1.15	.00	3.38	1.45	.45	1.22	.65	1.80	16.97

Measurements of the flow near the dam site below Tonto Creek were begun in February, 1901, and are still continued. Besides these there are records of flow of Salt River above the mouth of the Verde from April, 1897, to November 30, 1899, and of Salt River below the Verde for several previous years and for 1900. The measurements below the Verde are made in the various irrigation canals. When there was a surplus of water, there was no necessity for accurate measurements, and at such times the results are only approximate. They are, however, for a considerable period the only available records, and are considered sufficiently accurate to justify their use. To render available the latter records in estimating the water supply to the proposed reservoir, it is necessary to determine the proportion of water received from the Verde and Salt. For this purpose the records are taken where these two streams were separately observed, and the ratio of each stream to their sum is computed month by month, with results as given below:

Proportion of total flow of Salt and Verde rivers discharged by Salt River.

Month.	1897.	1898.	1899.	1901.	Mean.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	
January		0.587	0.520	0.615	0.574
February		.555	.541	.539	.545
March		.531	.660	.631	.607
April		.720	.740	.855	.772
May	0.813	.719	.862	.836	.808
June	.720	.647	.590	.728	.672
July	.575	.573	.564	.567	.570
August	.495	.503	.619	.425	.510
September	.419	.516	.469	.657	.515
October	.654	.494	.328		.492
November	.523	.522	.461		.502
December	.515	.504			



A GORGE OF SALT RIVER LOOKING DOWNSTREAM.

B. SALT RIVER RESERVOIR SITE, LOOKING UPSTREAM.

The values thus obtained cover the periods from August 1, 1888, to December 31, 1894, and from December 1, 1899, to December 31, 1900. Observations of the discharge of Salt River above the Verde were taken direct from February 4, 1895, to July 31, 1896. During this period direct observations were made by the Hudson Reservoir Company, and from April 20, 1897, to November 30, 1899, by the Geological Survey. The discharge from February 27 to December 31, 1901, was observed at the reservoir site and requires no reduction.

The storage of flood waters on Salt River will not only utilize such waters by holding them until needed, but will greatly increase the utility of the floods of the Verde River by providing a much larger irrigated area to receive such floods, and at the same time holding back the waters of the Salt as long as the Verde is able to fill the requirements. An examination of the records shows that with such manipulation the Verde will usually supply all requirements during the four months of December, January, February, and March, and that a very large proportion of the flood waters of the Verde which now run to waste would be thus utilized.

The record since 1888 is taken in connection with the proposed reservoir and 660,000 acre-feet annual consumption, and from this a table has been constructed, showing what would take place if the past experience should be repeated after the construction of the reservoir.

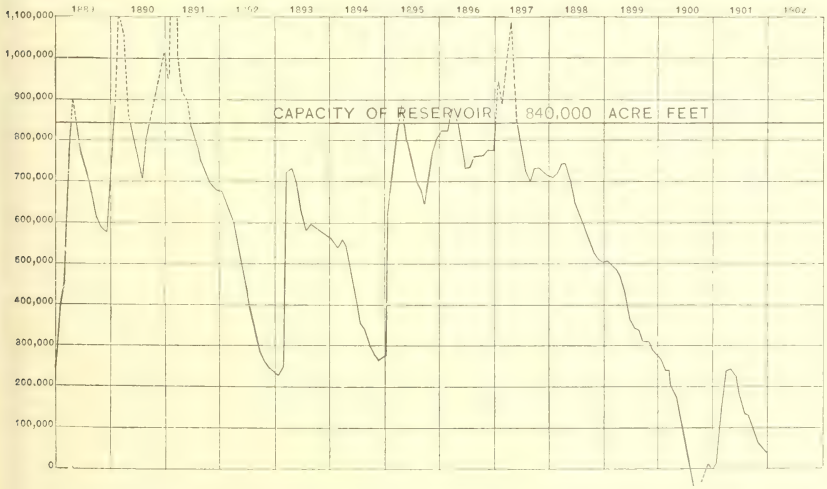


FIG. 2.—Fluctuations of Salt River reservoir, operated in connection with Verde River, under a duty of 660,000 acre-feet per annum.

The drainage area between the reservoir and the mouth of the Verde is nearly 10 per cent of the whole area above the Verde, and therefore to reduce the discharge of the Salt to that intercepted at the reservoir, the discharge at the mouth of the Verde was reduced by about 10 per cent, this percentage being slightly modified according to the season. From these data and computations the tables of dis-

charges for the Verde, at McDowell, and Salt River at the reservoir site, were obtained. In reducing the discharge of Arizona dam to the required amounts, the following percentages were used:

Estimated monthly discharge at McDowell and Salt River reservoir sites, in percentage of total at Arizona dam.

Month.	Verde at McDowell.	Salt at reservoir site.	Month.	Verde at McDowell.	Salt at reservoir site.
January	0.42	0.52	August	0.49	0.46
February	.45	.50	September	.48	.46
March	.39	.56	October	.50	.44
April	.20	.72	November	.50	.45
May	.19	.76	December	.50	.45
June	.30	.63			
July	.42	.52	Mean	.40	.54

Estimated monthly discharge of Salt River at reservoir site.

[Drainage area, 5,756 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1888.[a]						
August			161	9,902	.03	.03
September			161	9,580	.03	.03
October	154	132	146	8,957	.02	.02
November	2,592	191	379	22,545	.06	.07
December	19,570	249	3,014	185,367	.52	.58
The year				236,351		
1889.[a]						
January	12,976	866	2,092	190,185	.54	.62
February	1,970	767	1,303	72,289	.23	.24
March	18,925	1,995	4,897	301,178	.85	.98
April	4,002	1,797	2,862	170,289	.50	.56
May	1,356	473	790	48,562	.14	.16
June	387	224	296	17,618	.05	.06
July	682	174	257	15,871	.04	.05
August	347	179	192	11,797	.03	.03
September	539	179	240	14,260	.04	.04
October	310	140	194	11,906	.03	.03
November	283	239	259	15,422	.04	.04
December	11,417	251	2,561	157,360	.44	.51
The year	18,925	174	1,420	1,026,737	.24	3.32
1890.[a]						
January	8,190	716	2,591	159,324	.45	.52
February	71,644	523	5,049	280,192	.88	.92
March	9,648	1,437	3,596	221,139	.62	.71
April	1,495	986	1,325	78,826	.23	.26
May	1,040	479	695	42,720	.12	.13
June	423	250	322	19,155	.06	.07
July	453	206	272	16,758	.05	.06
August	3,538	512	1,787	109,906	.31	.36
September	1,695	334	1,076	64,018	.20	.22
October	3,285	331	1,218	70,502	.21	.24
November	13,727	345	2,123	126,297	.37	.41
December	13,665	500	2,817	173,218	.49	.56
The year	71,644	206	1,906	1,362,055	.33	4.46
1891.[a]						
January	8,906	551	1,777	109,254	.31	.36
February	150,000	413	19,408	1,077,834	3.37	3.47
March	4,968	753	2,768	170,204	.48	.55
April	2,182	1,654	1,922	114,390	.33	.37
May	2,243	1,461	1,834	112,761	.32	.37
June	1,132	587	842	50,083	.15	.17
July	502	312	388	23,884	.07	.08
August	346	236	261	16,066	.04	.05

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.

A. DRILLING PARTY ON SALT RIVER, LINE A OF BORINGS.

B. SALT RIVER DAM SITE, LOOKING DOWNSTREAM.

Estimated monthly discharge of Salt River at reservoir site.—Continued.

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1891.[a]						
September	605	220	378	22,500	.07	.08
October	273	203	227	13,933	.04	.05
November	283	207	230	13,710	.04	.04
December	311	264	295	14,151	.05	.06
The year	150,000	203	2,529	1,738,770	.44	5.65
1892.						
January	445	318	352	21,614	.06	.07
February[b]	234	204	221	12,274	.04	.04
March[b]	268	206	230	14,118	.04	.04
April[b]	450	268	315	18,765	.05	.06
May[b]	760	185	365	22,431	.06	.07
June[b]	157	76	110	6,523	.02	.02
July	267	168	189	11,606	.03	.03
August	259	152	186	11,427	.03	.03
September	180	150	157	9,361	.03	.03
October	770	144	196	12,066	.03	.03
November	392	203	231	13,736	.04	.04
December	266	236	253	14,578	.04	.05
The year	770	76	234	168,499	.04	.51
1893.						
January	286	286	286	17,585	.05	.06
February	5,312	275	747	41,459	.13	.13
March	207,208	331	7,734	475,523	1.34	1.54
April	1,782	508	1,043	62,079	.18	.20
May	1,520	257	602	37,010	.14	.16
June	222	93	143	8,509	.02	.02
July	592	145	279	17,138	.05	.06
August	1,164	219	753	46,301	.13	.15
September	1,116	272	508	30,218	.09	.10
October	655	242	331	20,345	.05	.06
November	305	252	266	15,852	.04	.04
December	293	281	283	17,404	.05	.06
The year	207,208	93	1,081	789,423	.18	2.58
1894.						
January	327	286	303	18,609	.05	.06
February	316	263	288	15,995	.05	.05
March	1,430	294	760	46,761	.13	.15
April	968	342	616	36,673	.10	.11
May	356	241	271	16,636	.05	.06
June	280	139	166	9,897	.03	.03
July	276	82	148	9,081	.02	.02
August	866	131	412	25,343	.07	.08
September	685	133	280	16,642	.05	.06
October	628	107	213	13,094	.04	.05
November	272	186	207	12,290	.03	.03
December	738	209	397	24,432	.07	.08
The year	1,430	82	338	245,453	.06	.78
1895.						
January[c]	46,806	744	5,390	331,358	.93	1.07
February[c]	3,697	368	1,373	76,239	.24	.25
March[c]	3,173	1,253	1,738	106,838	.30	.35
April[c]	2,704	961	1,711	105,144	.30	.33
May[c]	940	480	673	41,356	.12	.14
June[c]	475	193	309	18,372	.05	.05
July[d]	353	120	160	9,816	.03	.03
August[d]	1,022	209	440	27,168	.08	.09
September[d]	499	166	242	14,425	.04	.04
October[d]	7,194	279	857	52,675	.15	.17
November[d]	3,994	309	764	45,467	.13	.15
December[d]	995	430	603	37,104	.10	.12
The year	46,806	120	1,188	865,962	.20	2.80

[a] Obtained by taking proportional part of the discharge of Salt River at Arizona dam.
[b] Approximate; filled in from minimum discharge recorded in same months for 1900.
[c] Results obtained by taking from the published discharge of Salt River at McDowell Eighteenth Ann. Rept., Pt. IV, p. 298) that percentage of the whole that represents the discharge of the Salt between the mouth of the Verde and the reservoir site.
[d] Results obtained by taking proportional part of the discharge of Salt River at Arizona dam. Mr. Trott's figures used in computation.

Estimated monthly discharge of Salt River at reservoir site—Continued.

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1896.[a]						
January	547	416	447	27,497	.08	.09
February	479	339	393	22,572	.07	.07
March	1,769	428	844	51,925	.15	.17
April	1,487	636	941	55,986	.16	.18
May	669	352	485	29,861	.08	.09
June	292	150	204	12,245	.03	.03
July	5,528	111	779	47,928	.13	.15
August	4,997	256	797	49,017	.14	.16
September	4,280	241	534	31,752	.09	.10
October	555	265	398	24,484	.07	.08
November	672	300	443	26,375	.08	.09
December	400	293	317	19,479	.05	.05
The year	5,528	111	548	399,121	.08	1.26
1897.						
January[a]	19,422	312	2,647	162,777	.46	.53
February[a]	2,494	543	970	53,871	.17	.18
March[a]	5,762	1,013	2,160	132,808	.38	.44
April	9,743	1,136	4,281	254,787	.74	.83
May[b]	1,910	608	1,114	68,461	.19	.22
June[b]	591	180	358	21,305	.06	.07
July[b]	285	78	175	10,173	.03	.03
August[b]	755	157	410	25,176	.07	.08
September[b]	1,269	338	673	40,049	.11	.12
October[b]	1,010	228	549	33,755	.09	.10
November[b]	290	257	273	16,225	.05	.06
December[b]	292	251	270	16,590	.05	.06
The year	19,422	78	1,157	835,977	.20	2.72
1898.[c]						
January	1,077	240	338	20,808	.06	.07
February	743	473	587	32,511	.10	.10
March	858	509	688	42,261	.12	.14
April	1,036	496	757	45,000	.13	.14
May	704	261	448	27,513	.08	.09
June	351	182	237	14,112	.04	.04
July	800	166	408	25,085	.07	.08
August	1,211	130	385	23,658	.06	.07
September	868	106	338	20,136	.06	.07
October	180	106	156	9,538	.03	.03
November	232	182	202	12,041	.03	.03
December	402	232	300	18,401	.05	.06
The year	1,211	106	404	291,064	.07	.92
1899.[c]						
January	762	249	356	21,906	.06	.07
February	461	332	386	21,421	.06	.06
March	617	404	480	29,499	.08	.09
April	575	437	536	32,025	.09	.10
May	475	204	308	18,926	.05	.06
June	493	161	204	12,119	.03	.03
July	1,410	155	444	27,282	.08	.09
August	3,325	166	671	41,240	.11	.13
September	1,228	165	298	17,675	.05	.06
October	738	158	253	15,548	.04	.05
November	215	157	203	12,040	.03	.03
December[d]	203	142	195	12,009	.03	.03
The year	3,325	142	361	261,690	.06	.80
1900.[e]						
January	242	222	234	14,388	.04	.05
February	234	204	221	12,274	.04	.04
March	268	206	230	14,118	.04	.05
April	450	268	315	18,765	.05	.06
May	760	185	365	22,431	.06	.07

[a] Mr. Trotts's figures used in these computations. Results obtained by taking proportional parts of the discharge of Salt River at Arizona dam.

[b] Results obtained by taking from the discharge registered at McDowell that percentage which represents the discharge of the river between McDowell and the reservoir site.

[c] Results obtained by taking from the discharge registered at McDowell that part of percentage that represents the discharge of the river between McDowell and reservoir site.

[d] Trott's figures.

[e] Computations made from Mr. F. P. Trott's figures.

A. SALT RIVER DAM SITE, LOOKING UPSTREAM.

B. SOUTH ABUTMENT OF SALT RIVER DAM, LOOKING DOWNSTREAM.

Estimated monthly discharge of Salt River at reservoir site—Continued.

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1900.[a]						
June	157	76	110	6,523	.02	.02
July	130	45	64	3,933	.01	.01
August	521	63	142	8,711	.02	.02
September	290	88	116	6,898	.02	.02
October	359	95	161	9,902	.03	.03
November	2,222	146	387	23,055	.06	.07
December	245	184	202	12,396	.03	.03
The year	2,222	45	212	153,394	.035	.47
1901.						
January[a]	1,735	201	454	27,945	.08	.09
February[b]	4,172	928	2,414	134,047	.42	.44
March[b]	3,468	740	1,423	87,472	.25	.29
April[b]	1,562	620	1,050	62,442	.18	.20
May[b]	1,267	462	735	45,203	.13	.15
June[b]	508	147	288	17,262	.05	.06
July[b]	3,556	71	346	21,296	.06	.07
August[b]	2,221	207	529	32,504	.09	.10
September[b]	670	123	309	17,907	.05	.06
October[b]	215	117	152	9,334	.03	.03
November[b]	215	183	189	10,629	.03	.03
December[b]	195	183	190	11,663	.03	.03
The year	4,172	71	672	477,704	.11	1.55
1902.						
January	238	170	186	11,423	.03	.03
February	220	184	194	10,852	.03	.03

[a] Computations made from Mr. F. P. Trott's figures.
[b] Computations made from observations by United States Geological Survey.

History of Salt River Reservoir, operated from 1889 to 1901, in connection with the unregulated Verde River, with annual use of 660,000 acre-feet.

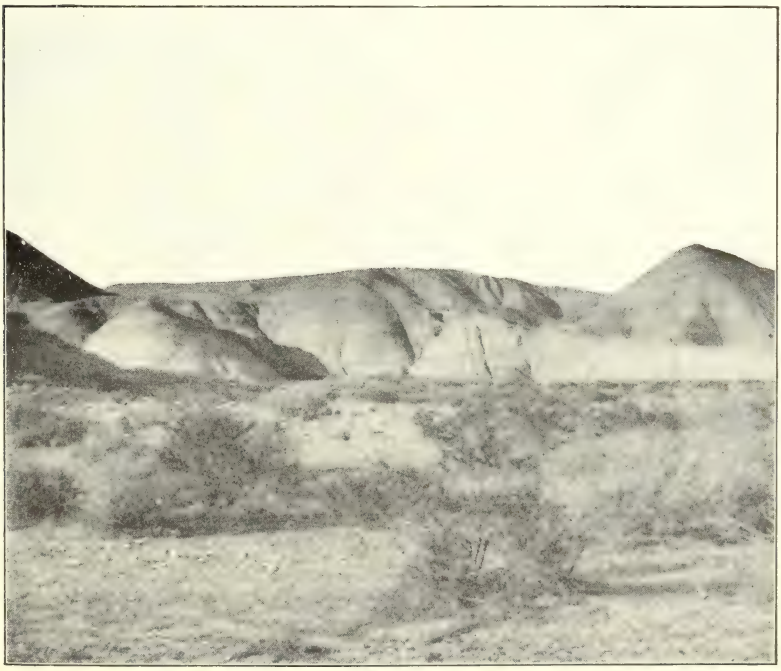
[Capacity of reservoir, 840,745 acre-feet. Annual use, 660,000 acre-feet.]

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
1889.		*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
January	6	39,600	153,611	0	0.25	6,874	1,718	1,718	190,185	{200,000 {388,467	.....
February	7	46,200	65,059	0	.34	8,676	2,950	2,950	72,289	457,806	.....
March	8	52,800	209,747	0	.50	10,895	5,448	5,448	301,178	753,536	.....
April	9	59,400	47,302	12,098	.58	12,361	7,169	19,267	170,289	840,745	63,813
May	11	72,600	12,141	60,459	.83	13,398	11,120	75,330	48,562	813,977	.....
June	11	72,600	8,390	64,210	.92	12,950	11,914	76,124	17,618	755,471	.....
July	10	66,000	12,819	53,181	1.00	12,403	12,403	65,584	15,871	705,758	.....
August	10	66,000	12,556	53,444	1.08	11,821	12,767	66,210	11,797	651,345	.....
September	9	59,400	14,880	44,520	.83	11,231	9,332	53,841	14,260	611,764	.....
October	7	46,200	13,530	32,670	.50	10,796	5,398	38,068	11,906	585,602	.....
November	6	39,600	17,136	22,464	.42	10,596	4,450	26,914	15,422	574,110	.....
December	6	39,600	174,845	0	.33	11,433	3,773	3,773	157,360	727,697	.....
1890.											
January	6	39,600	128,685	0	.25	13,233	3,308	3,308	159,324	840,745	42,968
February	7	46,200	252,172	0	.34	13,459	4,576	4,576	280,192	840,745	275,616
March	8	52,800	153,967	0	.50	13,459	6,729	6,729	221,139	840,745	214,410
April	9	59,400	21,896	37,504	.58	13,459	7,806	45,310	78,826	840,745	33,516
May	11	72,600	10,680	61,920	.83	13,362	10,190	72,110	42,720	811,355	.....
June	11	72,600	9,121	63,479	.92	12,935	11,900	75,379	19,155	755,131	.....
July	10	66,000	13,535	52,465	1.00	12,408	12,408	64,873	16,758	707,016	.....
August	10	66,000	117,074	0	1.08	12,659	13,671	13,671	109,906	803,251	.....
September	9	59,400	66,802	0	.83	13,404	11,125	11,125	64,018	840,745	15,399
October	7	46,200	80,116	0	.50	13,459	6,729	6,729	70,502	840,745	63,773
November	6	39,600	140,331	0	.42	13,459	5,652	5,652	126,297	840,745	120,645
December	6	39,600	192,464	0	.33	13,459	4,440	4,440	173,218	840,745	168,778

History of Salt River Reservoir, operated from 1889 to 1901, etc.—Continued.

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
1891.		*Acre-ft.*	*Acre-ft.*	*Acre-ft*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
January	6	39,600	88,244	0	.25	13,459	3,365	3,365	109,204	840,745	105,839
February	7	46,200	970,051	0	.34	13,459	4,576	4,576	1,077,834	840,745	1,073,258
March	8	52,800	118,535	0	.50	13,459	6,730	6,730	170,204	840,745	163,474
April	9	59,400	31,775	27,625	.58	13,459	7,806	35,431	114,390	840,745	78,959
May	11	72,600	28,190	44,410	.83	13,459	11,170	55,580	112,761	840,745	57,181
June	11	72,600	23,849	48,751	.92	13,459	12,382	61,133	50,083	829,695	.....
July	10	66,000	19,291	46,709	1.00	13,231	13,231	59,940	23,884	793,639	.....
August	10	66,000	17,113	48,887	1.08	12,814	13,839	62,726	16,066	746,977	.....
September	9	59,400	23,478	35,922	.83	12,438	10,323	46,245	22,500	719,232	.....
October	7	46,200	15,833	30,367	.50	12,138	6,069	36,436	13,933	696,729	.....
November	6	39,600	15,233	24,367	.42	11,840	4,973	29,340	13,710	681,099	.....
December	6	39,600	20,168	19,432	.33	11,744	3,875	23,307	14,151	674,943	.....
1892.											
January	6	39,600	17,458	22,142	.25	11,698	2,925	25,067	21,614	671,490	.....
February	7	46,200	11,746	34,454	.34	11,525	3,918	38,372	12,274	645,392	.....
March	8	52,800	7,087	45,713	.50	11,151	5,575	51,288	14,118	608,222	.....
April	9	59,400	4,604	54,796	.58	10,684	6,197	60,992	18,765	565,995	.....
May	11	72,600	5,935	66,665	.83	10,183	8,452	58,213	22,431	507,782	.....
June	11	72,600	3,588	69,012	.92	9,282	8,549	77,561	6,523	436,744	.....
July	10	66,000	9,374	56,626	1.00	8,518	8,518	65,144	11,606	383,206	.....
August	10	66,000	12,172	53,828	1.08	7,792	8,415	62,243	11,427	332,210	.....
September	9	59,400	9,768	49,632	.83	7,098	5,891	55,523	9,361	286,048	.....
October	7	46,200	13,712	32,488	.50	6,621	3,310	35,798	12,066	262,316	.....
November	6	39,600	15,263	24,337	.42	6,300	2,646	26,983	13,736	249,069	.....
December	6	39,600	17,309	22,291	.33	6,202	2,046	24,337	14,578	239,310	.....
1893.											
January	6	39,600	14,204	25,396	.25	6,061	1,515	26,911	17,585	229,984	.....
February	7	46,200	25,502	20,698	.34	6,133	2,085	22,783	41,459	248,660	.....
March	8	52,800	331,168	0	.50	9,533	4,767	4,767	475,523	719,416	.....
April	9	59,400	17,244	42,156	.58	12,328	7,150	49,306	62,079	732,189	.....
May	11	72,600	9,252	63,348	.83	12,223	10,145	73,493	37,010	695,706	.....
June	11	72,600	4,052	68,548	.92	11,589	10,662	79,210	8,509	625,005	.....
July	10	66,000	13,842	52,158	1.00	10,825	10,825	62,983	17,138	579,160	.....
August	10	66,000	49,321	16,679	1.08	10,297	11,120	27,800	46,301	597,661	.....
September	9	59,400	31,532	27,868	.83	12,168	10,099	37,967	30,218	589,912	.....
October	7	46,200	23,120	23,080	.50	10,666	5,333	28,413	20,345	581,844	.....
November	6	39,600	17,613	21,987	.42	10,561	4,435	26,422	15,852	571,274	.....
December	6	39,600	19,388	20,212	.33	10,464	3,453	23,665	17,404	565,013	.....
1894.											
January	6	39,600	15,030	24,570	.25	10,347	2,587	27,157	18,609	556,465	.....
February	7	46,200	14,395	31,805	.34	10,234	3,480	35,285	15,995	537,175	.....
March	8	52,800	32,565	20,235	.50	10,254	5,127	25,362	46,761	558,574	.....
April	9	59,400	10,187	49,213	.58	10,279	6,162	55,375	36,673	539,872	.....
May	11	72,600	4,159	68,441	.83	9,860	8,184	76,625	16,636	479,883	.....
June	11	72,600	4,713	67,887	.92	9,040	8,317	76,204	9,897	413,579	.....
July	10	66,000	7,334	58,666	1.00	8,173	8,173	66,839	9,081	355,821	.....
August	10	66,000	26,966	39,034	1.08	7,510	8,111	47,145	25,343	334,019	.....
September	9	59,400	17,365	42,035	.83	7,052	5,853	47,888	16,642	302,773	.....
October	7	46,200	14,880	31,320	.50	6,855	3,427	34,747	13,094	281,120	.....
November	6	39,600	13,656	25,944	.42	6,601	2,772	28,716	12,290	264,694	.....
December	6	39,600	27,147	12,453	.33	6,554	2,162	14,615	24,432	274,511	.....
1895.											
January	6	39,600	248,225	0	.25	9,039	2,260	2,260	352,508	624,759	.....
February	7	46,200	93,747	0	.34	11,579	3,937	3,937	80,251	701,073	.....
March	8	52,800	228,734	0	.50	12,611	6,305	6,305	112,461	807,229	.....
April	9	59,400	30,591	28,809	.58	13,459	7,806	36,615	110,678	840,745	40,547
May	11	72,600	15,864	56,736	.83	13,392	11,115	67,851	43,533	816,427	.....
June	11	72,600	9,104	63,496	.92	12,987	11,948	75,444	19,339	760,422	.....
July	10	66,000	8,916	57,084	1.00	12,417	12,417	69,501	12,543	703,464	.....
August	10	66,000	22,074	43,926	1.08	11,828	12,774	56,700	35,909	682,673	.....
September	9	59,400	10,473	48,927	.83	11,617	9,642	58,569	19,577	643,681	.....
October	7	46,200	20,630	25,570	.50	11,772	5,886	31,456	99,856	712,081	.....
November	6	39,600	27,550	12,050	.42	12,607	5,253	17,303	81,878	776,656	.....
December	6	39,600	24,042	15,558	.33	13,006	4,292	19,850	54,601	811,407	.....
1896.											
January	6	39,600	25,382	14,218	.25	13,235	3,309	17,527	28,900	822,780	.....
February	7	46,200	22,577	23,623	.34	13,296	4,520	28,143	27,380	822,017	.....
March	8	52,800	40,798	12,002	.50	13,459	6,780	18,782	72,863	840,745	35,353
April	9	59,400	21,776	37,624	.58	13,459	7,806	45,430	57,061	840,745	11,631
May	11	72,600	9,430	63,170	.83	13,277	11,020	74,190	27,424	793,979	.....
June	11	72,600	7,133	65,467	.92	12,719	11,701	77,168	13,328	730,139	.....
July	10	66,000	44,241	21,759	1.00	12,425	12,425	34,184	39,292	735,247	.....

A. MARICOPA COUNTY WATER-STORAGE COMMISSIONERS INSPECTING PLANE-TABLE WORK.



B. CLAY HILLS, NORTH EDGE OF RESERVOIR SITE.

History of Salt River Reservoir, operated from 1889 to 1901, etc.—Continued.

Month.	Per cent annual.	Water required for irrigation and other use.	Furnished by Verde.	Required from reservoir.	Depth of evaporation.	Area exposed to evaporation.	Loss by evaporation.	Total evaporation and use.	Inflow.	Balance in reservoir.	Overflow.
1896.		*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Feet.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*	*Acre-ft.*
August	10	66,000	57,541	8,459	1.08	12,593	13,600	22,059	49,017	762,205	.....
September	9	59,400	37,273	22,127	.83	12,710	10,549	32,676	31,752	761,281	.....
October	7	46,200	31,161	15,039	.50	12,700	6,350	21,389	24,484	764,376	.....
November	6	39,600	32,226	7,374	.42	12,780	5,367	12,741	26,375	778,010	.....
December	6	39,600	23,808	15,792	.33	12,840	4,237	20,029	19,479	777,460	.....
1897.											
January	6	39,600	150,258	0	.25	13,459	3,365	3,365	162,777	840,745	96,127
February	7	46,200	53,871	0	.34	13,459	4,576	4,576	53,871	840,745	49,295
March	8	52,800	104,350	0	.50	13,459	6,730	6,730	132,808	840,745	126,078
April	9	59,400	99,084	0	.58	13,459	7,806	7,806	254,787	840,745	246,981
May	11	72,600	20,143	52,457	.83	13,459	11,170	63,627	68,461	840,745	5,034
June	11	72,600	10,524	62,076	.92	13,248	12,188	74,264	21,305	787,786	.....
July	10	66,000	8,643	57,357	1.00	12,681	12,681	70,038	10,173	727,921	523,515
August	10	66,000	28,318	37,682	1.08	12,249	13,229	50,910	25,176	702,187	.....
September	9	59,400	61,584	0	.83	12,225	10,171	10,171	40,049	732,065	.....
October	7	46,200	21,154	25,046	.50	12,400	6,200	31,246	33,755	734,574	.....
November	6	39,600	16,443	23,157	.42	12,345	5,185	28,342	16,225	722,457	.....
December	6	39,600	17,290	22,310	.33	12,228	4,035	26,345	16,590	712,702	.....
1898.											
January	6	39,600	16,884	22,716	.25	12,156	3,039	25,755	20,808	707,755	.....
February	7	46,200	29,357	16,843	.34	12,190	4,145	20,628	32,511	719,638	.....
March	8	52,800	41,547	11,253	.50	12,387	6,198	17,451	42,261	744,448	.....
April	9	59,400	22,894	36,506	.58	12,524	7,364	43,870	45,000	745,578	.....
May	11	72,600	12,762	59,838	.83	12,328	10,231	70,069	27,513	703,022	.....
June	11	72,600	9,333	63,267	.92	11,744	10,804	74,071	14,112	643,162	.....
July	10	66,000	21,462	44,538	1.00	11,153	11,153	55,688	25,085	612,560	.....
August	10	66,000	25,840	40,160	1.08	10,845	11,713	51,873	23,658	584,345	.....
September	9	59,400	21,397	38,003	.83	10,528	8,738	46,741	26,136	557,740	.....
October	7	46,200	10,999	35,201	.50	10,194	5,097	40,298	9,538	526,980	.....
November	6	39,600	12,236	27,364	.42	9,928	4,170	31,534	12,041	507,487	.....
December	6	39,600	19,399	20,201	.83	9,780	3,227	23,428	18,401	502,460	.....
1899.											
January	6	39,600	22,919	16,681	.25	9,763	2,441	19,122	21,906	505,244	.....
February	7	46,200	20,232	25,968	.34	9,741	3,312	29,279	21,421	497,386	.....
March	8	52,800	17,539	35,261	.50	9,645	4,823	40,084	29,499	486,801	.....
April	9	59,400	14,983	44,417	.58	9,341	5,418	49,835	32,025	468,991	.....
May	11	72,600	10,342	62,258	.83	8,990	7,462	69,720	18,726	418,197	.....
June	11	72,600	9,967	62,633	.92	7,873	7,243	69,876	12,119	360,440	.....
July	10	66,000	24,183	41,817	1.00	7,667	7,667	49,484	27,282	338,238	.....
August	10	66,000	28,856	37,144	1.08	7,481	8,079	45,223	41,240	334,255	.....
September	9	59,400	22,371	37,029	.83	7,259	6,025	43,054	17,675	308,876	.....
October	7	46,200	34,749	11,451	.50	7,082	3,541	14,992	15,548	309,432	.....
November	6	39,600	13,874	25,726	.42	6,973	2,929	28,755	12,040	292,817	.....
December	6	39,600	14,677	24,923	.33	6,602	2,178	27,101	12,009	277,765	.....
1900.											
January	6	39,600	13,281	26,319	.25	6,568	1,642	27,961	14,388	264,192	.....
February	7	46,200	12,273	32,927	.34	6,320	2,149	36,076	12,274	240,390	.....
March	8	52,800	11,092	41,708	.50	5,935	2,967	44,675	14,118	209,833	.....
April	9	59,400	7,298	52,102	.58	5,404	3,134	55,236	18,765	173,362	.....
May	11	72,600	7,083	65,517	.83	4,450	3,693	69,210	22,431	126,583	.....
June	11	72,600	3,840	68,760	.92	3,477	3,199	71,959	6,523	61,147	.....
July	10	66,000	3,630	62,370	1.00	1,440	1,440	63,810	3,933	1,270	.....
August	10	66,000	10,226	55,774	1.08	0	0	0	8,711	.....	45,793
September	9	59,400	8,097	51,303	.83	0	0	0	6,898	.....	44,405
October	7	46,200	12,602	33,598	.50	0	0	0	9,902	.....	-23,696
November	6	39,600	28,178	11,422	.42	401	168	11,590	23,055	11,465	.....
December	6	39,600	15,150	24,450	.33	382	126	24,576	12,396	.....	715
1901.											
January	6	39,600	28,704	10,896	.25	549	137	11,033	27,945	16,912	.....
February	7	46,200	103,249	0	.34	3,112	1,058	1,058	134,047	149,901	.....
March	8	52,800	63,688	0	.50	5,417	2,709	2,709	87,472	234,664	.....
April	9	59,400	10,938	48,462	.58	6,151	3,568	52,030	62,442	245,076	.....
May	11	72,600	8,606	63,994	.83	6,065	5,034	69,028	45,203	221,251	.....
June	11	72,600	6,222	66,378	.92	5,465	5,027	71,405	17,262	167,108	.....
July	10	66,000	12,916	53,084	1.00	4,436	4,436	57,520	21,296	131,884	.....
August	10	66,000	38,561	27,439	1.08	4,130	4,460	31,899	32,504	132,489	.....
September	9	59,400	5,514	53,886	.83	3,780	3,137	57,023	17,907	93,373	.....
October	7	46,200	8,210	37,990	.50	3,004	1,502	39,492	9,334	63,215	.....
November	6	39,600	15,238	24,362	.42	2,290	962	25,363	10,629	48,481	.....
December	6	39,600	16,485	23,115	.33	1,761	581	23,696	11,663	36,346	.....

This table shows that if the proposed reservoir were operated in conjunction with the natural flow of the Verde River, and an annual supply of 660,000 acre-feet were desired, this could have been furnished every year in the record except 1900. In that year there would have been a shortage of about 16 per cent. It is believed that such a shortage is permissible in a storage project if it does not occur oftener than once in say ten years, which is the fact in the present case.

The duty of 660,000 acre-feet per annum is that of the combined Salt and Verde rivers, with a reservoir on Salt River operated in conjunction with the Verde, the waters of Salt River being held in the reservoir as long as the waters of the Verde are sufficient to supply demands. If the flood waters of the Verde are to be stored and used independent of Salt River they will not be available for this use, and the manipulation of Salt River reservoir will be radically different. Under these conditions the draft on the reservoir becomes constant the year around; the requirement for storage is lessened, and the irrigation duty of Salt River alone is of course much less. Our records indicate that a duty of about 450,000 acre-feet can be depended upon by using the rest of our storage capacity for reserve storage.

SALT RIVER RESERVOIR.

BORINGS.

Borings were made to bed rock at 31 points in the canyon, on four different lines. The first trial was made near the upper end of the canyon near the site selected by the Hudson Reservoir Company. Five holes were here drilled to rock, the depth in two of them being 44 and 64.5 feet. These results are shown in fig. 3. Another site was then selected about 1,600 feet downstream, and conditions were so much more favorable that a more thorough exploration was made, and the greatest depth being less than half that found above, the lower site was decided upon. Fig. 4 shows profiles of these borings. Following is a complete list of the borings.

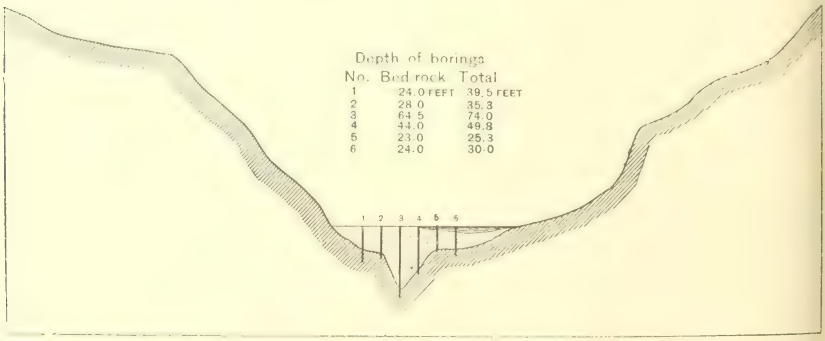
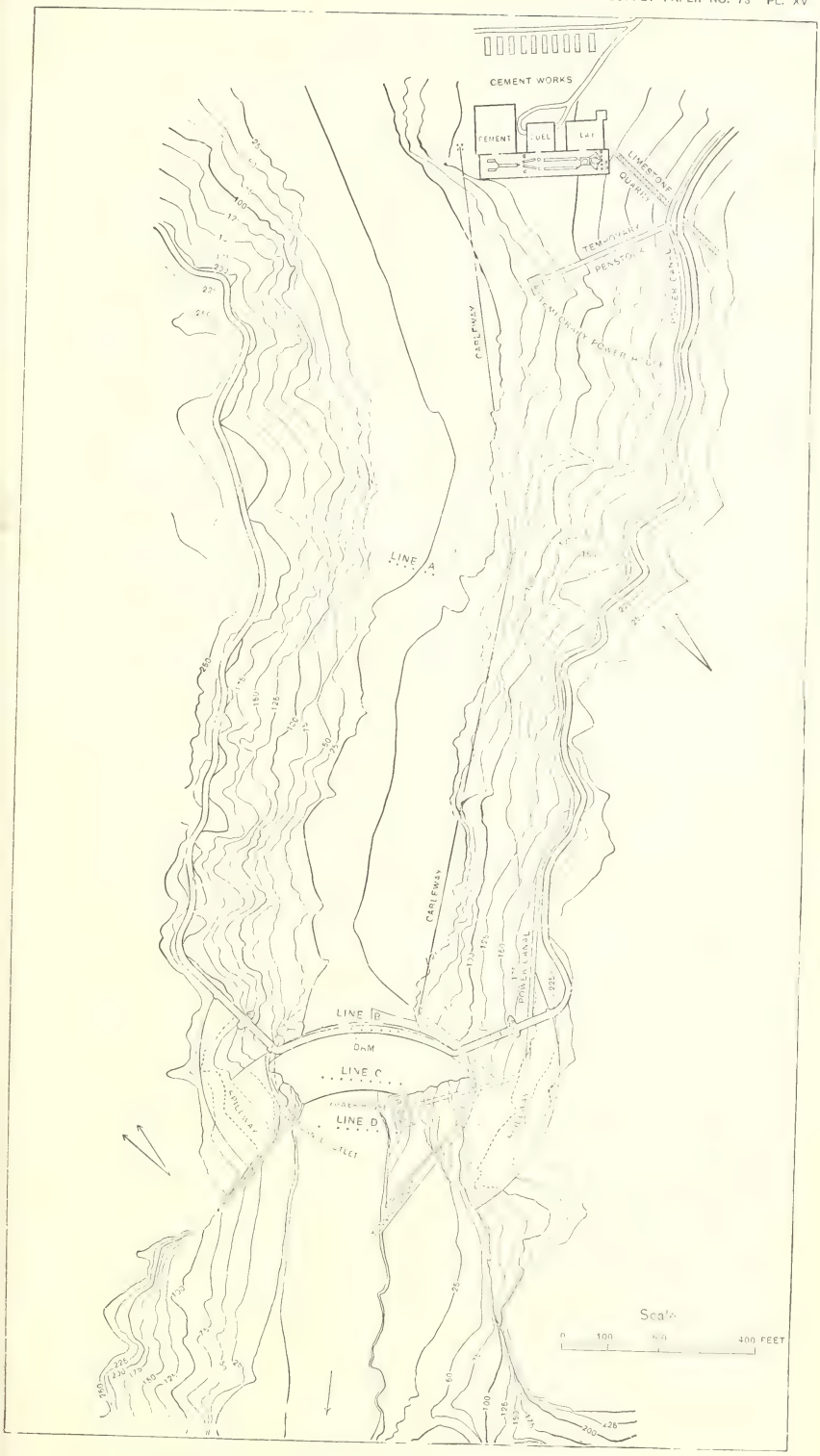


FIG. 3.—Profile of borings at Hudson Reservoir Company's dam site.



PLAN OF DAM, POWER PLANT, AND CEMENT FACTORY.

Borings at Salt River dam site—Continued.

No.	Bed rock.	Total depth.	Character of rock.
Line B, 1,000 feet below line A.	*Feet.*	*Feet.*	
1	22.5	22.5	Red sandstone.
2	26.7	31.7	Do.
3	25.5	25.5	Do.
4	25.8	31.3	Do.
5	28.0	28.0	Do.
6	25.0	31.3	Do.
7	24.7	24.7	Do.
8	22.2	26.7	Do.
9	20.0	20.0	Do.
Line C, 100 feet below line B.			
1	22.0	22.0	Red sandstone.
2	21.0	25.9	Do.
3	22.5	27.0	Do.
4	22.0	22.0	Do.
5	23.0	33.4	Do.
6	24.0	24.0	Do.
7	23.8	39.0	Do.
8	22.0	22.8	Do.
9	24.6	27.0	Do.
Line D, 100 feet below line C.			
1	.....	.....	
2	23.5	28.0	Black slate.
3	.....	.....	
4	23.5	26.4	Black slate.
5	25.0	.....	Do.
6	31.0	34.5	Do.
7	30.3	30.7	Do.
8	21.5	24.2	Do.
9	.....	.....	Do.
10	21.5	23.0	Do.

CAPACITY OF RESERVOIR.

The capacity of the reservoir was determined by a plane-table survey for each 10-foot contour to a height of 200 feet above the bed of the river in the gorge. These capacities are given in the following table:

Capacity of Salt River reservoir.

Height above low water.	Area.	Capacity of section.	Total capacity.
Feet.	*Acres.*	*Acre-feet.*	*Acre-feet.*
10	24	120	120
20	128	760	880
30	224	1,760	2,640
40	401	3,125	5,765
50	694	5,475	11,240
60	1,085	8,895	20,135
70	1,458	12,715	32,850
80	2,103	17,805	50,655
90	2,930	25,165	75,820
100	3,682	33,060	108,880
110	4,391	40,365	149,245
120	5,536	49,635	198,880
130	6,394	59,650	258,530
140	7,293	68,435	326,965
150	8,411	78,520	405,485
160	9,664	90,375	495,860
170	10,769	102,165	598,025
180	12,158	114,635	712,660
190	13,459	128,085	840,745
200	14,617	140,380	981,125

It will be noticed that for a dam of a height of less than 100 feet the capacity of the reservoir formed is not extraordinary, but above this height it increases more rapidly, and at a height of 200 feet is nearly a million acre-feet. It would be entirely practicable to construct a reservoir of several times this capacity, but this is not justified by the conditions; the limit to the economical height of dam is determined by the supply of water available for storage.

PLANS FOR THE DAM.

The gorge on Salt River is an especially favorable site for a masonry dam, and the most permanent, conservative, and secure form of high dam that is known to engineering science can be constructed. The formation is sedimentary, with the strata inclined at an angle of about 30° to the horizonal, dipping toward the reservoir, a most favorable condition for retaining stored waters and for the stability of the dam. The foundation and abutment of hard, tough, fine-grained sandstone are all that could be desired. Building stone of the same material is at hand, and above the site. As elsewhere set forth, good Portland cement can be made in the vicinity. Sand for mortar can be obtained from the river bed, but will have to be washed and screened, and it is thought that the best plan will be to manufacture sand by crushing quartzite, which occurs in abundance near the site. This will provide an ideal sand, and as power is abundant its cost will not be great.

The dam must be so designed and constructed as to be safe from destruction by any or all of the forces acting upon it. It is possible for a masonry dam to fail in any one of three ways: 1. By overturning; 2, by sliding on the base, or on any horizontal joint; 3, by crushing its foundation or masonry near the base. A factor of safety of at east two is secured against overturning by so designing the dam that under all conditions the resultant of all the forces acting will fall within the middle third of any horizontal joint. This also eliminates the possibility of any tensile strains in the masonry, a very desirable result. The same condition also secures safety against sliding, which is insured in a still greater degree by constructing the masonry of random rubble, and by the use of hydraulic mortar, bonding it together and to its base, so that it becomes a true monolith—a part of the solid rock to which it is firmly joined. Under these conditions a large margin of safety is provided, as the structure can not slide without shearing the masonry. In addition to these precautions the dam planned is to be built in the form of a circular arch, greatly increasing its safety against both sliding and overturning. In fact, neither can occur without overcoming the gravity and cohesion of the masonry, and also crushing the masonry or abutments. The total factor of safety against failure by the first and second methods can not be exactly known, but it is unquestionably very great. The third

method, that of the crushing of the masonry, is not affected by the curved plan, and there is room for considerable difference of opinion as to what are safe limits of pressure. The best guide, when intelligently followed, is the experience of the past. The following table gives pressures in some existing structures:

Pressures on masonry in existing structures.

Structure.	Material.	Pressure per square foot.	Authority.
		Tons.	
Bridge, Pont-y-Prydd, Wales	Limestone rubble, lime mortar.	20.7	I. O. Baker.
Brooklyn Bridge	Granite masonry	39.5	Duryea & Mayer.
Washington Monument, in wind.	Cut marble	25.4	Col. T. L. Casey.
St. Louis Bridge, before completion.	Cut limestone	38.0	History St. Louis Bridge, p. 370.
South Street Bridge, Philadelphia.	do	15.7	Trans. Am. Soc. C. E., Vol. VII, p. 305.
Rookery Building, Chicago	Cut granite	30.0	I. O. Baker.
Bear Valley dam	Granite rubble	40.0	J. D. Schuyler.
All Saints' Church, Angers	Forneaux stone	43.0	J. T. Fanning, p. 403.
Chapter House, Elgin	Red sandstone	20.0	Do.
St. Paul's, London	Portland limestone	19.7	Do.
St. Peter's, Rome	Calcareous tufa	16.7	Do.
Various arch bridges	Cut masonry	60.0	Do.
Quaker Bridge dam (projected).	Rubble masonry	15.0	Rep. Aqueduct Com., p. 55.
Almanza dam (300 years old)	do	14.3	Edward Wegman, p. 24.

Various experimental tests.

Material crushed.	Pressure per square foot.	Authority.
	Tons.	
Concrete prisms cut from Vrynwy dam	181	Sir Andrew Clark.
Granite ashlar, with mortar 1:2	583	Austrian Society E. & A.
Sandstone rubble, mortar 1:2	255	Do.
Sandstone rubble, mortar 1:3½	184	Do.
Gravel concrete 1:2:3	128	Do.
Gravel concrete 1:3:5	66	Do.

Two cubes of 1 cubic inch each were cut from briquets of neat cement, manufactured from materials obtained near the site. These were tested at the United States Navy-Yard, in Washington.

Sample No. 1 crushed at 6,690 pounds, or 482 tons per square foot.

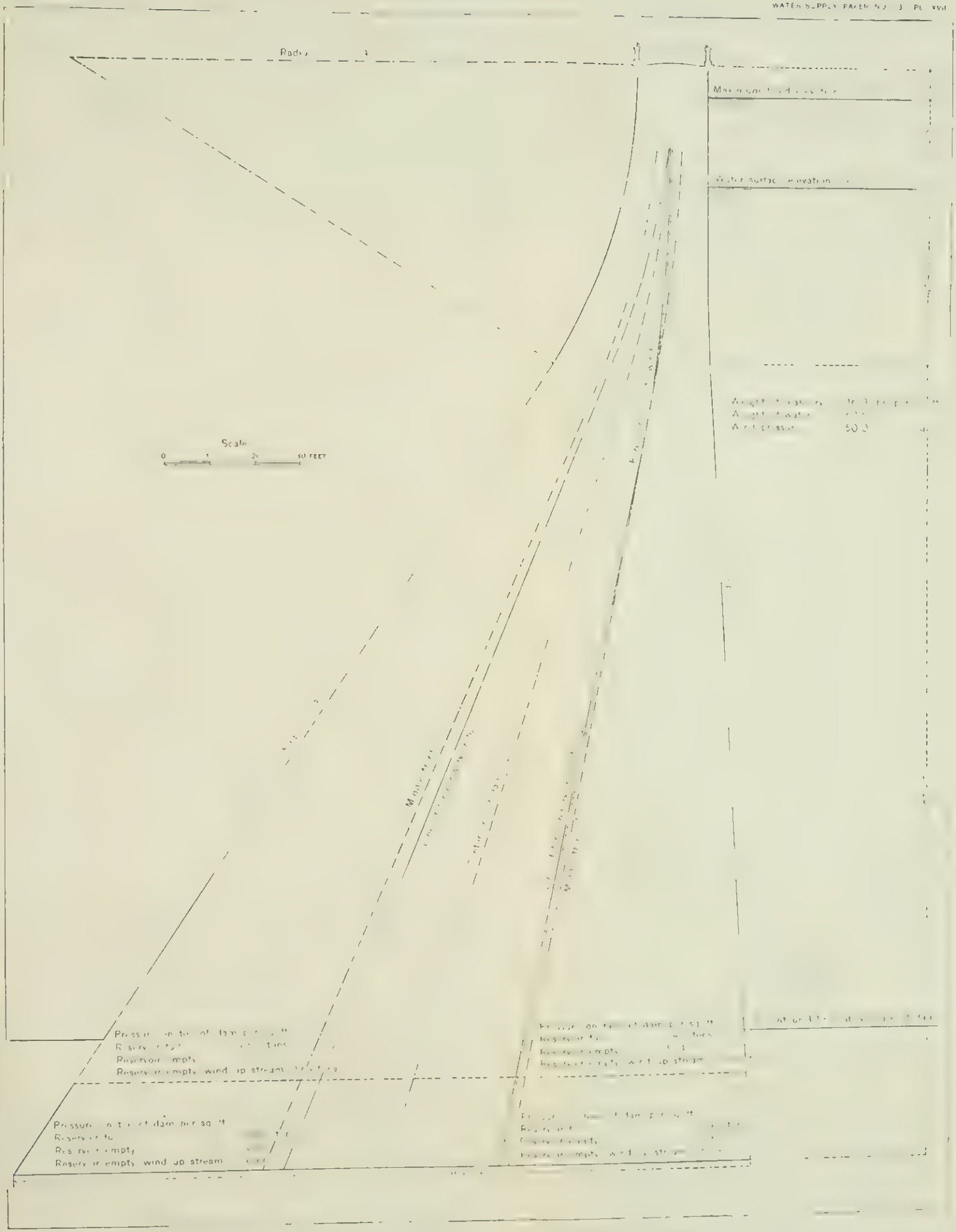
Sample No. 2 crushed at 8,840 pounds, or 636 tons per square foot.

Two cubes with edges of 2 inches were cut from samples of the rock to be used in Salt River dam, and crushed in the testing machine at the United States Navy-Yard, in Washington.

Sample No. 1 crushed at 59,650 pounds, being 14,912 pounds per square inch, or 1,074 tons per square foot.

Sample No. 2 crushed at 100,000 pounds, this being 1,800 tons per square foot. These results are so high that the strength of the rock is entirely eliminated from the discussion.

Test No. 4, in the above table, made by the Austrian Society, is very nearly representative of the masonry to be used in the proposed



MAXIMUM SECTION OF SALT RIVER DAM SHOWING FORCE LINES.

Salt River dam. A coefficient of safety of 10 in such masonry would permit of pressures of over 25 tons per square foot. As will appear later, the maximum pressures permitted in the proposed dam will be far below this figure.

The recorded failures of high masonry dams are as follows:

At the Habra dam in Algiers poor hydraulic lime was used, and a red earth with a large percentage of clay was used in the mortar instead of sand. This combination made a poor mortar, and the rock was also poor, both in the masonry and the foundation, being a calcareous grit of varying quality, and all porous. It is supposed that the failure occurred by the crushing of the foundation under a computed stress of 13.3 tons per square foot.

At the Bouzy dam in France the foundation was fissured and permeable and not on solid rock, allowing an immense upward hydrostatic pressure; the section was so light as to permit great tension in the masonry in the back. It was straight in plan, and when the reservoir was nearly filled the central portion of the wall was shoved forward about a foot, causing ruptures and leakage. This was afterwards repaired and the foundation reenforced. Six years later, when the reservoir was full, the dam suddenly overturned at a plane about 33 feet below the top. The above-recited defects were the undoubted cause.

At the Puentes dam in Spain the central portion of the dam was founded upon piles driven in earth. When the rising water applied a heavy hydrostatic pressure, this portion of the foundation suddenly gave way and left the top and ends of the dam standing in the form of an arched bridge.

The dam at Austin, Tex., was an overflow dam built of limestone rubble, the stone being very soft and of poor quality. The foundation was on a geological fault, and was of soft limestone, in thin, horizontal layers, which had little adhesion, and probably very little friction upon one another, and the failure, which was by sliding, is supposed to be due to this fact.

In all four of the above cases the foundation was defective. In three the stone was poor and in two the mortar was poor. All were straight in plan except the Puentes, which was polygonal in plan and arched upstream. This dam seems to have been very well planned and constructed, except for the one fatal defect of being founded on piles instead of solid rock.

All of the defects in these failures can easily be avoided in the proposed dam by a reasonable application of care and skill.

The proposed dam is designed to be 217 feet above low water in the river at the dam site and to store water at a maximum depth of 190 feet, the total height of dam above lowest foundation being about 247 feet. Spillways 20 feet deep will be excavated in the solid rock sides of the canyon and the rock used in the construction of the dam. The location lends itself admirably to a curved form of dam, this form

containing but little more material than a straight one of the same section. The proposed structure is to be built on a circular curve, convex upstream, the back having a radius of 400 feet and the face a shorter radius from the same center. The dam is to be of uncoursed rubble masonry and to have a section on modern conservative ideas as a simple gravity structure, and the added stability due to its curved form will greatly increase its factor of safety. The rock of which the dam will be constructed will be excavated from the spillways, and is a tough, close-grained sandstone. A sample was taken from each side of the canyon and tested for specific gravity in the laboratory of the United States Geological Survey. The following are the results of this test:

Specific gravities of two specimens of sandstone.

I. Determined on lumps.

A. In ordinary distilled water as quickly as possible.

No. 1.—Specific gravity, 2.42 at room temperature.

No. 2.—Specific gravity, 2.47 at room temperature.

B. After soaking in distilled water 24 hours.

No. 1.—Specific gravity, 2.44 at room temperature.

No. 2.—Specific gravity, 2.49 at room temperature.

C. After standing in distilled water under the air pump for 24 hours.

No. 1.—Specific gravity, 2.50 at room temperature.

No. 2.—Specific gravity, 2.52 at room temperature.

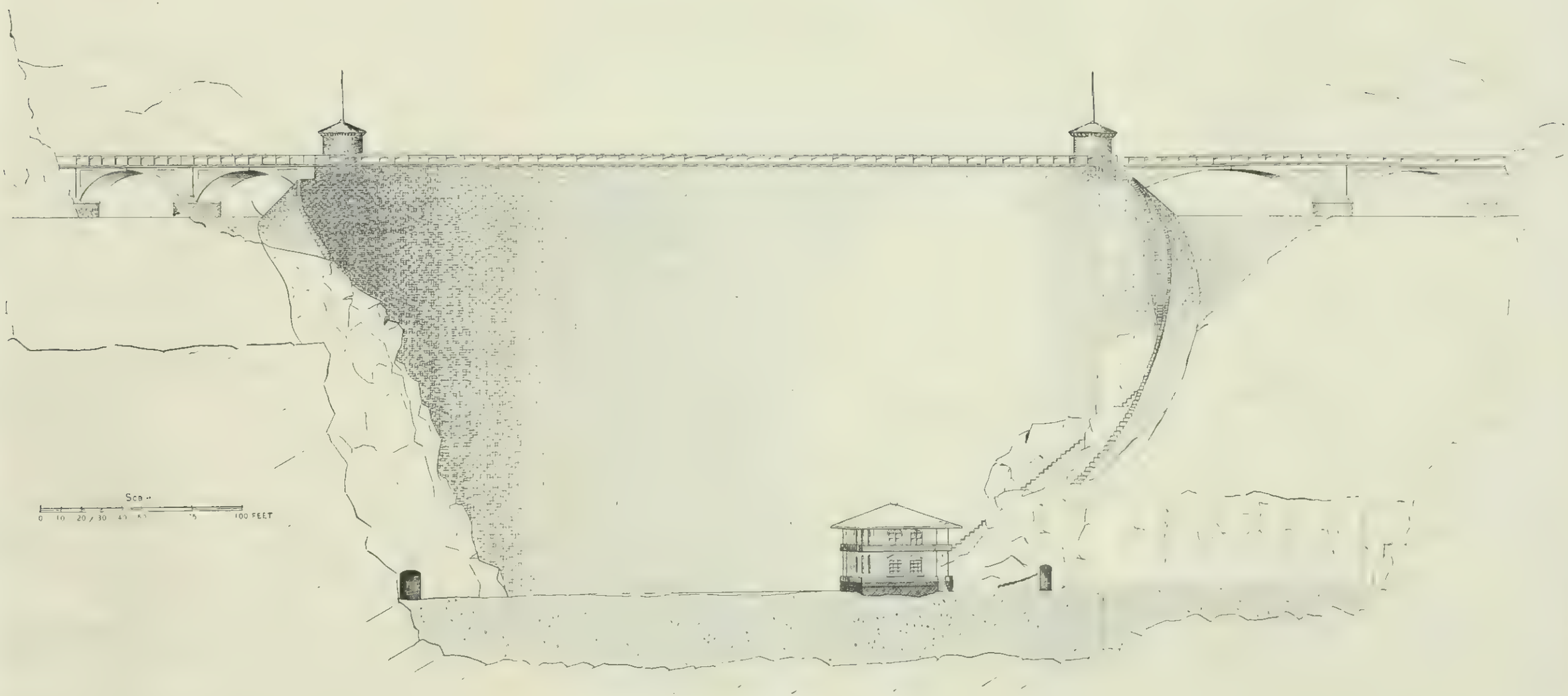
II. Determined on the powdered samples.

No. 1.—Specific gravity, 2.583 at 21.5 C., compared with water of same temperature.

No. 2.—Specific gravity, 2.611 at 17.5 C., compared with water of same temperature.

Tests for crushing were also made and are given on page 36.

The rock is to be used in as large pieces as practicable, in order to make the number of joints as few and the quantity of mortar as small as may be. It is estimated that the rock will occupy 70 per cent of the structure. Fifteen per cent will consist of cement mortar, in which the stones are bedded, and 15 per cent will consist of cement concrete rammed into the vertical joints. Taking the weight of the mortar as 115 pounds per cubic foot and that of the concrete as 130 pounds, the masonry will weigh, as nearly as can be estimated, 146 pounds to the cubic foot. On this estimate the strains have been computed and the section of the dam designed. As the dam is to serve as a highway, a top width of 16 feet has been adopted, with parapets along the sides. The section adopted is the smallest consistent with the necessary top width, and with the requirement that the resultants of all forces acting upon the dam shall be at all times within the middle third. The pressure on the toe when the reservoir is full will be 15.9 tons per square foot, computed on the assumption that the dam is a rigid monolith and nonelastic. Any elasticity it may have will tend to relieve this pressure. The maximum possible pressure, 16.64 tons, occurs at the heel when the reservoir is empty, with a strong wind blowing upstream.



ELEVATION OF SALT RIVER DAM

The table on p. 36 shows fourteen instances with pressures greater, some of them many times greater, than those in the proposed dam.

The following specifications are proposed for the dam:

SPECIFICATIONS FOR THE CONSTRUCTION OF THE DAM.

Diversion of the river.—The diversion of the river will be accomplished by means of sheet piling driven as deeply as practicable directly across the canyon, beginning at the south side and reaching as nearly as practicable to bed rock, the piling to be reenforced at and above the surface by a heavy wall of sand and gravel excavated from the site of the dam, the water to be diverted through the outlet tunnel, which will be constructed in advance. The gravel wall will be built at least 1 foot higher than the top of the outlet channel for three-fourths of its length, about 50 feet of the southern end of the embankment being left at an elevation 6 feet lower, to be utilized as a spillway for excessive floods which may occur too large for the capacity of the outlet tunnel. The excavation for foundation will begin at the southern wall of the canyon, and as rapidly as completed to solid foundation will be filled with masonry. As soon as 40 or 50 feet of the southern end of the foundation is completed, a wooden flume will be placed at the above-mentioned spillway on the embankment, reaching downstream over the completed portion of the foundation, discharging into the stream bed at least 300 feet downstream from the toe of the dam. This flume will be about 1,000 feet long, and in that distance will have a fall of nearly 8 feet, which will give it a high velocity and enable it to discharge any floods likely to occur. The pumps employed in drying the foundation excavations will discharge into this flume.

In case sheet piling can not be driven deep enough to cut off the underflow, pipes shall be driven along the line across the canyon and cement grout pumped in until the desired result is obtained.

Foundation.—All earth, sand, gravel, bowlders, disintegrated, loose, and seamed rock will be excavated and removed from the entire area of the base of the dam in order to secure a firm foundation on solid rock. Explosives shall not be used in excavating the rock unless absolutely necessary, and when used shall be only in small quantities and in shallow holes to avoid fracture of the rock forming the foundation of the dam. The entire foundation shall be thoroughly washed with wire brooms, first with water and then with thin cement grout. Throughout the length of the foundations a trench 6 feet wide and 6 feet deep, 15 feet from the heel of the dam and parallel thereto, shall be cut in the solid rock of the foundation.

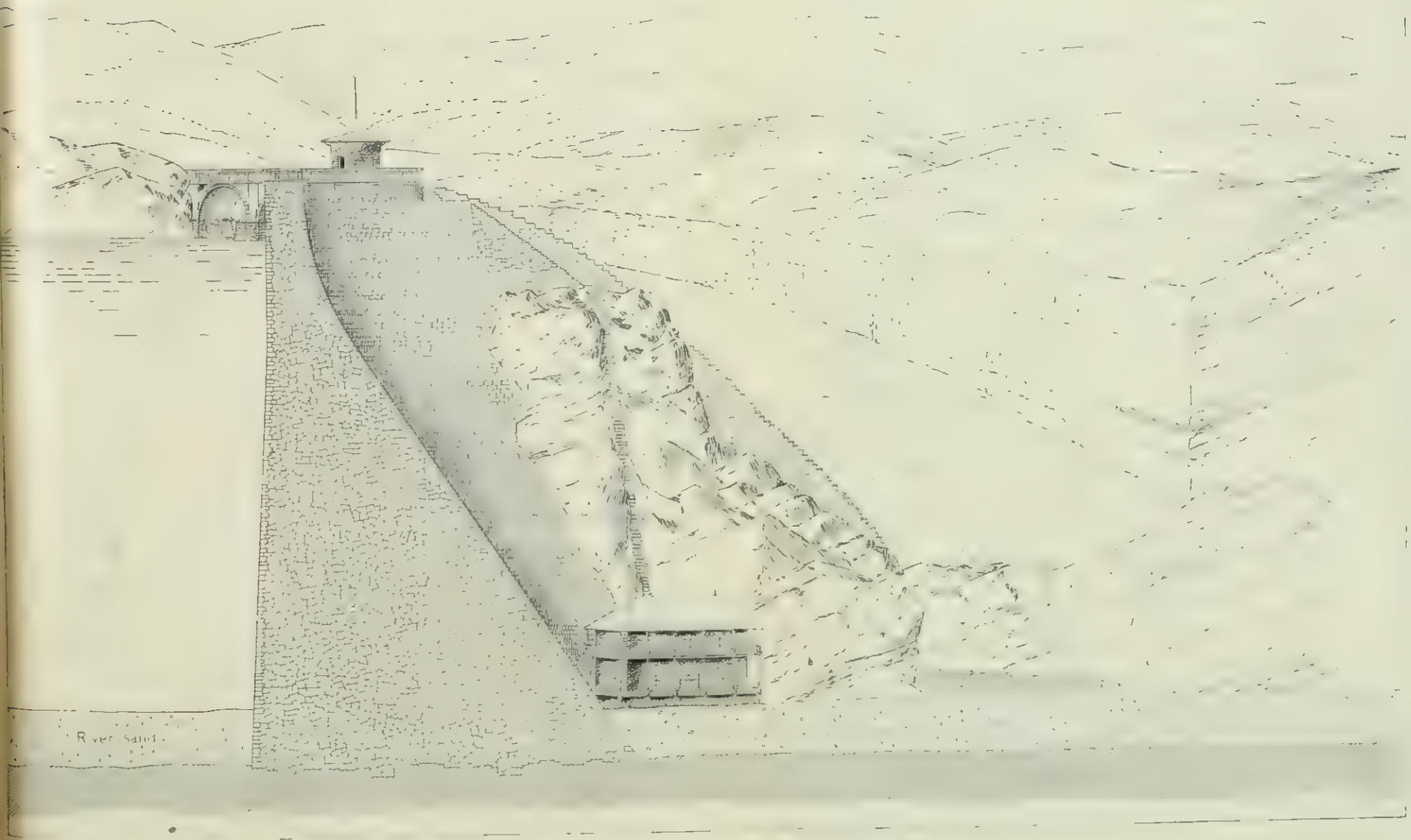
Masonry.—The main body of the dam shall be constructed of broken range cyclopean rubble. The stone shall be quarried from the walls on each side of the canyon, shown in the drawing as proposed spillways. If a sufficient quantity of hard, fine-grained stone can not be obtained in these spillways it shall be quarried elsewhere.

All stone shall be thoroughly washed and laid in Portland cement mortar, and each stone shall be laid on its largest bed. The stone for the upstream face shall be rough pointed, so as to lay with horizontal beds and vertical joints. No mortar joint in the face shall exceed 1 inch in thickness. At least one-fourth of the area in the face must be headers evenly distributed throughout the wall, and every header shall be laid over a stretcher of the underlying course. The stone shall be so arranged as to form a proper bond, in no case less than 1 foot, with the stone of the underlying course. The stretchers must not be less than 3 feet long, nor less than 2 feet in any other dimension. The headers must not be less than 6 feet in length nor less than 2 feet in any other dimension.

The body of the dam shall be composed of as large stone as practicable, well shaped, and laid so as to break joints and thoroughly bond the work in all directions. Each stone shall be laid on its largest face in a bed of Portland cement mortar of the quality hereafter specified. Vertical joints between the stones in the body of the dam must be nowhere less than 4 inches and must be carefully and thoroughly filled with Portland cement concrete, which shall be rammed into place by hand. To secure thorough bedding each stone must be lifted and the bed examined, to the end that all space in the dam not occupied by stone shall be absolutely filled with mortar, so as to make a water-tight construction. The masonry shall be kept wet during the time of construction. The aim shall be to use the largest proportion of stone and the smallest proportion of mortar and concrete in the dam that can be practicably secured. To this end facilities shall be provided for handling stones weighing 12 tons, and large stones shall be used as far as practicable. To the same end the stones shall be split from the large masses found in the quarry by the "plug-and-feather" method, or any similar process that may be found efficient in breaking the stones along regular lines, so that joints to be filled with mortar may be reasonably thin and uniform.

Mortar and concrete.—All mortar used in the lower 30 feet of the dam shall consist of 1 part of Portland cement, 2 parts of good sharp sand; and all concrete used in this portion of the dam shall consist of 1 part cement, 2 parts sand, and 3 parts of broken stone graded to such size as will pass through a screen with meshes 2 inches square. The mortar and concrete used in the upstream face of the dam for a thickness of 20 feet shall be of the quality above specified.

In all parts of the dam which are more than 20 feet from the upstream face and 30 feet from the base the mortar shall be 1 part Portland cement to 3 parts of sand, and concrete of 1 part Portland cement, 3 parts sand, and 4 parts broken stone of a size to pass through a screen with meshes 2 inches square. All mortar and concrete shall be thoroughly mixed as the work progresses and used so promptly that there will be no danger whatever of incipient setting of the cement pre-



SECTION OF DAM AND ELEVATION OF SPILLWAY AND POWER HOUSE

vious to the completion of the masonry in which it is placed. No cement shall be used until at least sixty days after its manufacture, and not until it shall show satisfactory tests according to the chemical and physical requirements adopted by the American Society of Civil Engineers.

The reason for using a larger percentage of cement in the base of the dam is that here will be the greatest pressures, and the higher percentage of cement will give a greater power of resistance to crushing. The high percentage of cement is maintained on the water face of the dam, all the way to the top, in order to render it as nearly impervious as possible.

It may be confidently predicted that a masonry dam at the proposed site, constructed on the above plans and specifications, would be absolutely permanent, "safe, solid, and secure for all ages to come," as truly as the "everlasting hills," of which it will become an integral part.

SEDIMENT.

Most of the streams of the southwest carry a considerable quantity of solid matter which causes annoyance in canals, and has a tendency to fill any reservoir constructed on the stream. This is true of the Rio Grande, Colorado, Pecos, and Gila rivers. There is silt also in the waters of Salt River, as shown by its occurrence in the canals, but it is not nearly as abundant as in the streams above mentioned. The basin tributary to the Salt River reservoir lies in large part in high timbered country, and includes the Apache Indian Reservation. These Indians constitute probably the most efficient forest patrol in the country, and their reservation is almost entirely covered with forest and grass. The basin of Tonto Creek, and a few other tributaries, however, are closely pastured and deliver some silt during sudden floods.

Observations of the amount of sediment carried give the results found in the following table:

Percentage of sediment found in Salt River water.

Date.	Sediment.	Total volume.
1901.	*Per cent.*	*Acre-feet.*
January	0.00026	9.27
February 1-15	.00053	34.42
February 16-28	.00012	8.28
March	.000099	9.53
April 1-18	.0000021	.06
April 19 to May 26	No sediment.	.00
May 27-31	.005895	28.74
June	No sediment.	.00
July	.003924	83.58
August	.004128	134.16
September	.0033323	23.85
October	.000054	5.04
November	.000058	.65
December	No sediment.	.00
Total for the year		337.58

NOTE.—From January 1 to April 18, 1901, observations were made at McDowell station; balance of the year at reservoir site.

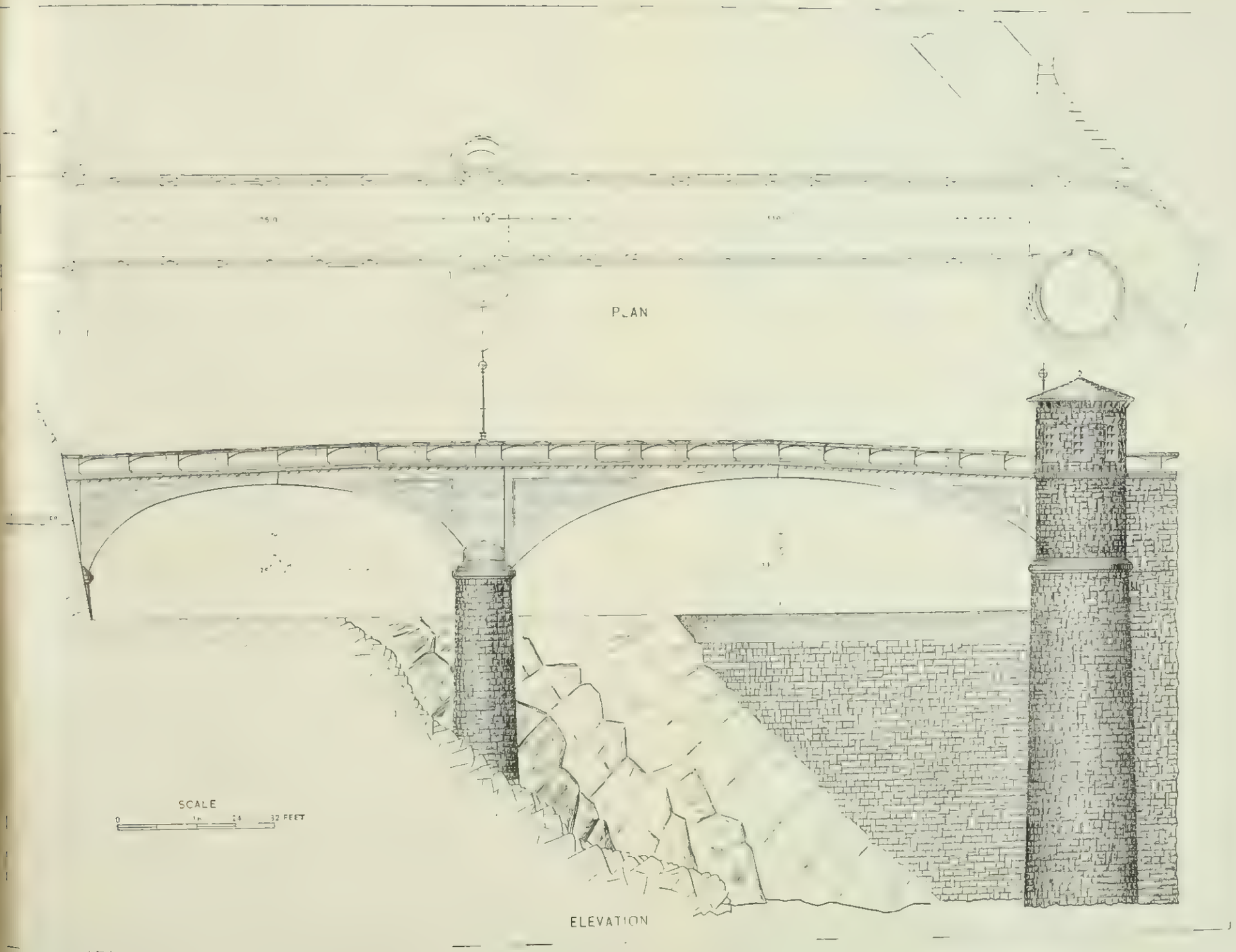
The above table shows that during the period covered by the observations the sediment carried was very small in amount, almost negligible, but the discharge during the year was far below the normal, and it is believed that the proportion of sediment shown by the observations was also below the normal. If we take 1,000 acre-feet as the average inflow of sediment, this will be nearly three times that observed during 1901, and yet it would require eight hundred years to fill the reservoir if none were drawn off. It would probably be one hundred years before the loss of storage capacity would be seriously felt and it would become necessary to resort to methods of clearing it out.

At all times when the river is in flood the water in the reservoir will be more or less turbid. The lower the stage of the reservoir and the greater the flood in the river the greater will be the percentage of sediment held in suspension. The greatest amount of sediment will usually be found in the lower layers of water, and it will therefore contribute to the maintenance of the storage capacity to draw all waters from the lowest possible point at all times. Two outlets are provided in the form of tunnels 10 by 13 feet, one around each end of the dam. It should be made an invariable rule that whenever water begins to run over the spillway the gates must be opened to full capacity, not only to draw off the maximum quantity of sediment but also to reinforce the spillway capacity as much as possible.

Experience at the Sweetwater and other reservoirs shows that the greatest deposits of sediment are in the deepest part of the reservoir, which in this case is near the dam. The above provision would dispose of a considerable portion of this, and any further provision for removing silt would be unnecessary for more than a century.

SPILLWAY PROVISION.

The greatest flood ever known in Salt River Valley occurred in February, 1891. It is described in the Twelfth Annual Report of the United States Geological Survey, and has been referred to on page 20 of this report. The maximum discharge of this flood was estimated at the almost incredible volume of 300,000 cubic feet per second. A freshet of less magnitude, but still very large, occurred in 1890. There is abundant evidence that there had been no flood approaching these in magnitude for a very long time. The drainage area from which this flood was drawn was considerably more than double the area tributary to the proposed Salt River reservoir, but the latter having more than the average precipitation, it is credited with 54 per cent of the total discharge under the discussion of "Water-supply" on page 26. A smaller drainage basin is, moreover, liable to a relatively higher flood discharge than a larger one, though the floods are of shorter duration. From the above considerations it is estimated that the maximum flood wave possible at Salt River reservoir is 220,000 cubic



ELEVATION OF BRIDGE SPILLWAY AND GATE TOWER

feet per second, reaching this amount by a rapid increase in volume, and declining somewhat less suddenly from the maximum to the normal discharge. On this assumption an examination has been made of the effect of such a flood upon the reservoir. It is assumed that the reservoir is full up to the bottom of the spillway, and that a great flood occurs, with a mean discharge for the first hour of 120,000 cubic feet per second, and increases its discharge 10,000 cubic feet per second during each hour for eleven hours, at the end of which time it has reached its maximum wave of 220,000 cubic feet per second. The discharge then decreases in an arithmetical progression for twenty hours, at the rate of 5,000 second-feet per hour, reaching a discharge of 120,000 second feet as a mean for the thirty-first hour.

This spillway as planned has a total length of 350 feet, and its bottom is 27 feet below the top of the dam. Its discharge capacity is computed from the formula $Q=H^{\frac{3}{2}}\ 1220=3.5\ LH^{\frac{3}{2}}$.

Effect of maximum flood on Salt River reservoir, with spillway 350 feet long, 190 feet above river bed.

[$Q=H^{\frac{3}{2}}\ 1220$.]

Hour.	Inflow.		Outflow.		Net rise.	Elevation.
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.		
					Feet.	*Feet.*
1	120,000	9,920	12,920	1,065	0.82	190.82
2	130,000	10,740	14,380	1,185	.87	191.69
3	140,000	11,570	16,560	1,365	.92	192.61
4	150,000	12,390	19,430	1,600	.97	193.58
5	160,000	13,320	22,920	1,890	1.01	194.59
6	170,000	14,040	27,190	2,245	1.03	195.62
7	180,000	14,870	31,600	2,610	1.06	196.68
8	190,000	15,690	36,730	3,035	1.08	197.76
9	200,000	16,520	42,360	3,500	1.10	198.86
10	210,000	17,350	48,460	4,000	1.11	199.97
11	220,000	18,170	54,980	4,540	1.12	201.09
12	215,000	17,760	61,590	5,085	1.03	202.12
13	210,000	17,350	67,940	5,610	.94	203.06
14	205,000	16,930	73,960	6,110	.86	203.92
15	200,000	16,520	79,620	6,575	.78	204.70
16	195,000	16,170	84,900	7,010	.71	205.41
17	190,000	15,690	89,790	7,415	.64	206.05
18	185,000	15,280	94,270	7,785	.57	206.62
19	180,000	14,870	98,340	8,120	.51	207.13
20	175,000	14,450	102,740	8,485	.45	207.58
21	170,000	14,040	105,300	8,695	.40	207.98
22	165,000	13,630	108,200	8,935	.35	208.33
23	160,000	13,220	110,810	9,150	.30	208.63
24	155,000	12,830	113,040	9,335	.26	208.89
25	150,000	12,390	114,920	9,490	.21	209.10
26	145,000	11,980	116,460	9,620	.17	209.27
27	140,000	11,570	117,630	9,720	.13	209.40
28	135,000	11,150	118,610	9,795	.10	209.50
29	130,000	10,740	119,250	9,850	.06	209.56
30	125,000	10,320	119,620	9,880	.03	209.59
31	120,000	9,920	119,760	9,892	.00	209.59
Capacity of spillway			123,120	10,170		210.00

At the end of the thirty-first hour the surface of the water has reached an elevation of 209.6 feet, or 7.4 feet below the top of the dam, and from that point begins to decline, the spillway having at this elevation a discharge of 119,760 cubic feet per second. The above-assumed flood wave might, therefore, be considerably exceeded

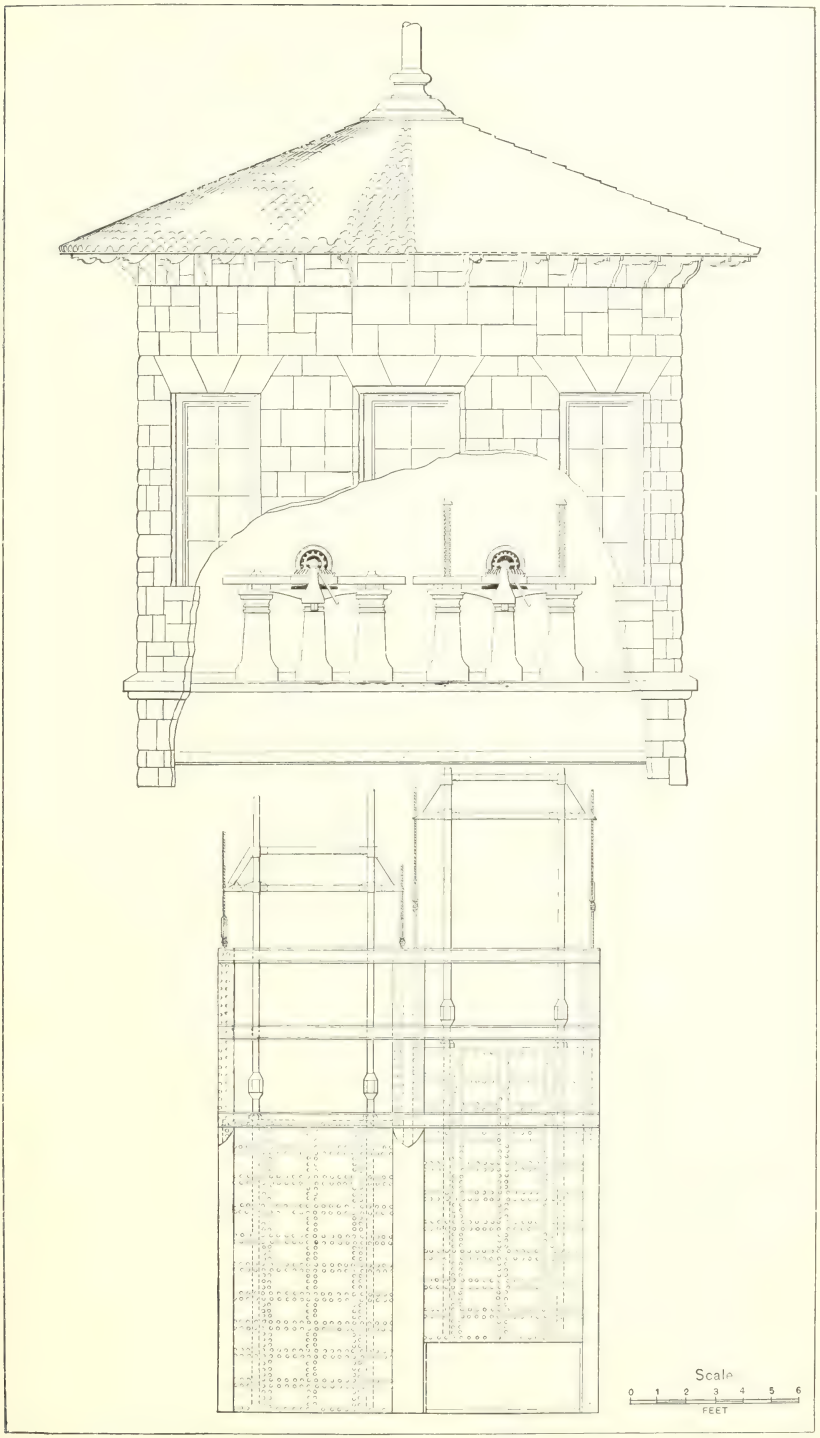
without flowing over the dam, and therefore the spillway provisions as planned are considered ample for all possible requirements. It should be noted, however, that the dam would not be injured nor endangered by a very considerable flow over the top.

OUTLET WORKS.

For the purpose of facilitating the discharge of sediment from the reservoir, and also to furnish the maximum reenforcement to the spillways, it has been decided to draw all water from the reservoir through large openings directly on the bottom. Accordingly the plan adopted is to have two tunnels dug through the solid rock, one on each side of the canyon. Each tunnel will be provided with two gates, each 6 feet by 10 feet 3½ inches, with a clear opening of 5 feet 4½ inches by 10 feet, making a total area of 215 square feet clear opening. This would have a discharge capacity of about 1,500 cubic feet per second with water standing in the reservoir on a level with the top of the tunnels. When the reservoir stands higher than this the head would, of course, increase the possible discharge, and when water begins to flow through the spillways the tunnel would have a discharge capacity of about 12,000 cubic feet per second, and with the spillways running full, about 14,000 cubic feet per second. The head on the lower sill of the outlet tunnels would be 190 feet with water standing at the level of the bottom of the spillways. This will be the maximum head frequently encountered, but the possible head would be 20 feet more, or 210 feet, with water flowing over the spillways 20 feet deep, which is considered the maximum head possible, encountered only at long intervals, if ever. This will produce a mean pressure of about 12,800 pounds per square foot on the gates, or a total on each gate of about 390 tons. These pressures and sizes require gates of great strength and efficient means of controlling their position.

Each gate is built of nine parallel 9-inch **I** beams, two channels horizontally, and three longitudinal beams, the whole inclosed by a half-inch plate solidly riveted to the beams and channels, so as to make the entire gate act as a girder. It will be the aim to make this girder water-tight on the edges and the side exposed to the water, but drainage holes will be provided on the lower side to discharge any chance leakage.

The pillar which will occupy the center of each tunnel is built of plates and angles in the form of a large **I** beam, and is reenforced on each side by a 12-inch **I** beam, and the whole is inclosed by a thin steel skin, to minimize the tendency to produce vibrations. The beams are so arranged as to diminish the contractions also, and thus increase the discharge. The sheet steel will be continued along the sides and bottom of the tunnel throughout its entire length. Under



ELEVATION OF TOWER, GATES, AND GATE LIFTS.

these arrangements the velocity of the water through the tunnel, running full, with the water in the reservoir at the level of the top of the tunnel, will be about 7 feet per second, and will increase to over 60 feet per second with the water 20 feet deep over the spillways. Each gate will be worked by two hollow rods running upward through the shaft and tower to the tower houses at the top of the dam, where they will be worked by screws operated by electric motors.

The hollow rods will consist of 3-inch, double-extra heavy steel drivepipe, and will work in guides, as shown in Pl. XXI. The upper section of rod which carries the thread for moving the gates will be solid.

The bearings for the gates will be upon solid steel rollers placed to eliminate friction. A general view is shown on Pl. XXII.

The steel is estimated at 8 cents per pound erected.

POWER PLANT.

In the construction of a great dam one of the most important elements is that of power. This is necessary on a large scale for drilling purposes, for handling rock, for mixing and handling mortar, and for crushing rock to be used in concrete. In the present case, furthermore, it has been found possible and very desirable to manufacture on the ground the large quantity of cement required in the dam. This would require about 300 horsepower day and night, for grinding rock and clinker, and for handling materials and running machinery. It is usual to provide such power by means of steam engines, but in the present case this is rendered very expensive by the scarcity of fuel. Coal, in quantities, now costs $10 per ton in Globe, and the wagon haul to the dam site would nearly double this. A limited amount of wood is available, but to secure the large quantity which would be required if it were the sole dependence for power would involve a long haul.

The best means for providing the necessary power is by the development of water power on the river. This will involve the construction of a diversion dam and canal, which can afterwards be utilized, if required, for sluicing accumulated silt out of the reservoir. The power developed can afterwards be used in the neighboring mines or transmitted to the valley below for pumping purposes. For either purpose it will be a valuable asset.

The standard canal section adopted has a bottom width of 8 feet, water depth of 3.5 feet, total depth of 4.5 feet, with side slopes of 1 to 1 in excavation and 1½ to 1 in embankment. Its slope will be 0.0006.

In the first 12,000 feet of the line the depth will be slightly increased to provide for seepage losses. Small drainage lines will be crossed by means of concrete culverts. Flume construction will be employed only where absolutely necessary, on account of its lack of perma-

nence. The adopted flume section is a rectangular box, 4 feet deep and 7 feet 8 inches wide inside, built of 2-inch redwood plank, supported by frame of native pine. Sawmills will be established near the line and logs floated down Salt River from the mountain valleys above. This native timber will also be used for false works and other temporary structures about the works. The details of flume construction are shown on Pl. XXIII.

There are to be two tunnels on the line, one 15,000 and one 18,000 feet in length. Both are to be in coarse gravel, and will be lined with concrete.

No detailed surveys have been made of the line, and the estimates which follow should be regarded as only approximate. The estimated cost of earth excavation is 15 cents per cubic yard, and of rock $1 per cubic yard.

The proposed canal would head some distance above the reservoir, follow above its water line, and finally discharge just below the dam, with an available head of about 180 feet. It is designed to deliver 100 cubic feet per second, and to develop a net energy of about 1,200 horsepower after deducting seepage, friction, and losses in water wheels, electric plant, etc. It is designed to use 900 horsepower at the dam and 300 horsepower at the cement mill.

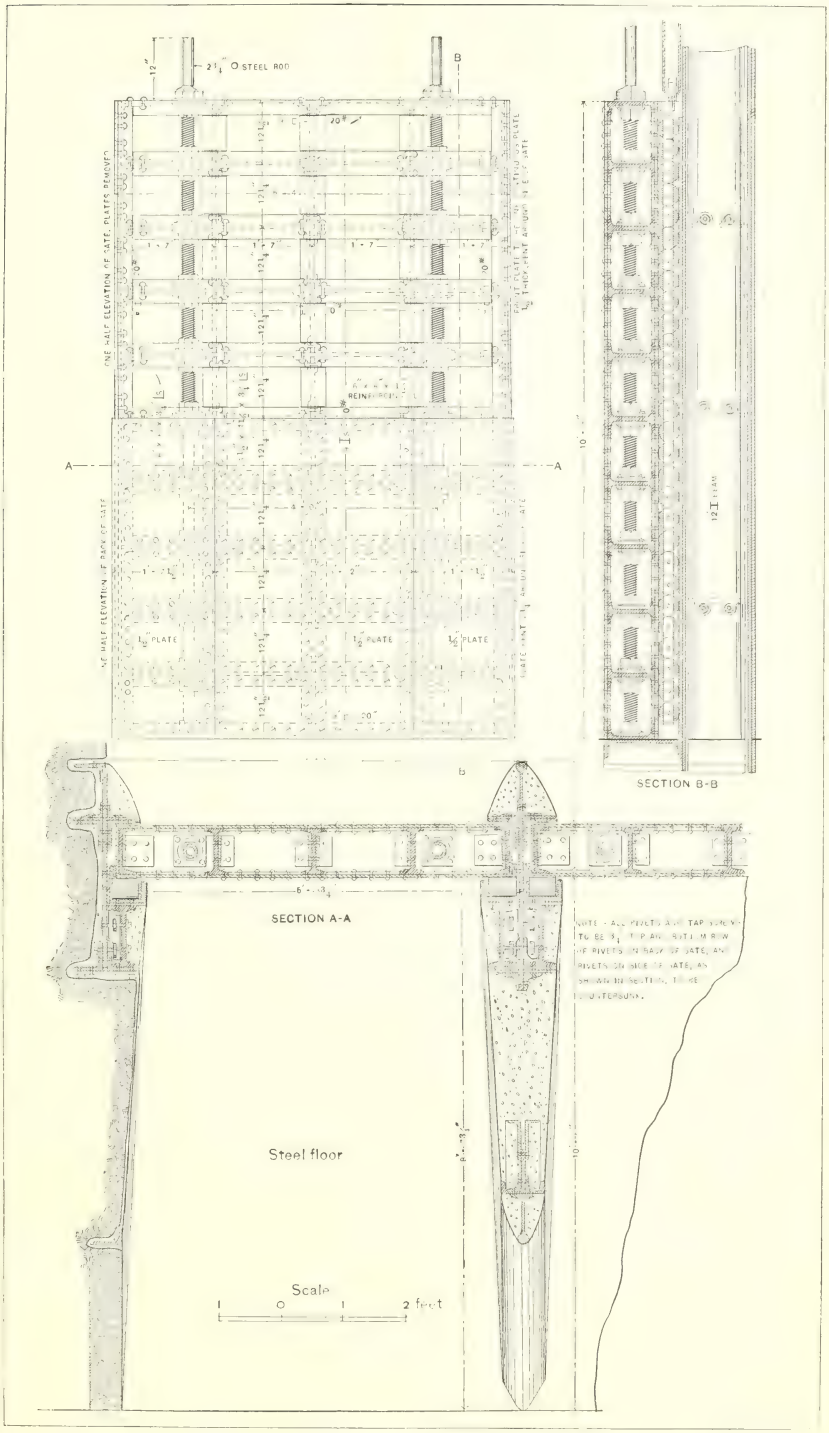
The power plant will consist of three units of 300 kilowatts each, one of which will be temporarily installed near the cement mill, to be used there in making cement and in drilling for the outlet tunnels, dam foundations, etc., before the permanent plant is installed, until it is desired to store water above the 25-foot contour of the reservoir, at which time the manufacture of cement should have been completed, when this unit will be placed alongside the other two below the dam. The two units placed below the dam will be at first protected by a temporary power house, until the foundation of the dam at that point is brought up to the level of the ground, when the stone power house will be built.

The windows of the power house will be 10 feet above the bed of the river, and the tailrace of the power house will be provided with a gate by which, if it ever becomes necessary, backwater from the discharge of the spillways can be prevented from entering the power house. At such times, perhaps once in twenty or thirty years, it may become necessary to close down the power plant for a few hours.

The following approximate estimate of the cost of the power installation has been prepared:

Estimated cost of power plant.

Diversion works:		
Dam	$10,000	
1,000 feet of flume	2,325	
75,200 feet of canal	58,975	
3,300 feet of tunnel, at $6	19,800	
		$91,100



ELEVATION AND SECTION OF OUTLET GATES.

Water wheels, etc.:		
9 wheels, shafts, nozzles, housings, etc	$7,350	
3 pairs couplings for attaching dynamos	555	
270 feet 52-inch pipe for penstock	1,600	
Receiver and 9 branches	1,555	
Freight on 140,000 pounds, at 3 cents	4,200	
Power house	10,000	
		$25,260
Electric plant:		
3 300-kilowatt dynamos and exciters	24,000	
Transformers and motors	35,000	
Transmission lines	1,000	
Freight and installation	12,000	
		72,000
Total cost of power plant		188,360

The power plant as planned is about what is necessary in the construction of the dam and the manufacture of cement. It contemplates the use of the entire flow of the Salt River at minimum stages, and hence is the maximum that can be made available at full head for use at all times. After the construction of the reservoir this power can be utilized for other purposes, but if constantly required will consume water from the reservoir during the winter months, when usually a sufficient supply for irrigation purposes can be obtained from the unregulated flow of the Verde River. If, however, the power is used exclusively for pumping water for irrigation, it will not be required during the season of high water on the Verde. When this supply becomes insufficient, it will be necessary to start the pumping plants and to draw water from the reservoir, which can be utilized at such times, both for power and irrigation; hence, if used exclusively for pumping, none will be wasted.

There are other power possibilities in this reservoir site by arranging to draw all irrigation water from the reservoir under a considerable head through turbines which can be used to develop power for pumping purposes. Such development, however, will be of a very different character from the works already planned. The water will be drawn under a variable head, and at times of extreme scarcity, when the reservoir may run nearly or quite empty, and when irrigation water is most needed, the head will be diminished and the water to be drawn will be insufficient or entirely lacking at times when the power for pumping is most needed, unless the duty of the reservoir is diminished to a sufficient extent to prevent this. It is probable, however, that such a utilization of the power could be profitably made. A decision on this point rests on the equation between the cost of necessary plant and the value of necessary storage capacity on the one side as against the value of the water pumped on the other side. There is, however, a limit to the availability of underground waters which can not be definitely known until an extensive trial is made by pumping on the large reservoir of water which seems to be stored

underground in Salt River Valley. The problem, however, is an attractive one, and deserves extensive study in connection with the utilization of Salt River reservoir.

CEMENT MANUFACTURE.

The natural topographic conditions of this site are very favorable for the construction of a masonry dam of the most conservative and permanent design yet devised. This form of construction, however, is rendered very expensive by the remoteness and difficulty of access to the site. There is a wagon haul of over 40 miles across mountainous country from the end of the railroad, which is a branch road with light traffic and high rates. It is estimated that cement would cost at the dam site about $9 per barrel. As over 100,000 barrels of cement would be required for the dam, such a price is a most serious handicap to the project, and presents a strong temptation to adopt a rock-fill type of structure which would be immensely cheaper. However, before deciding this important point, it was thought best to investigate the possibility of manufacturing cement in the vicinity, and, with this object, search was made in Tonto Basin for materials suitable for the purpose. Eight samples of rock and clay were sent in for analysis to E. A. Duryee, superintendent of the cement works at Colton, Cal. The analyses were as follows:

Analyses of rocks and clays from Tonto dam site.

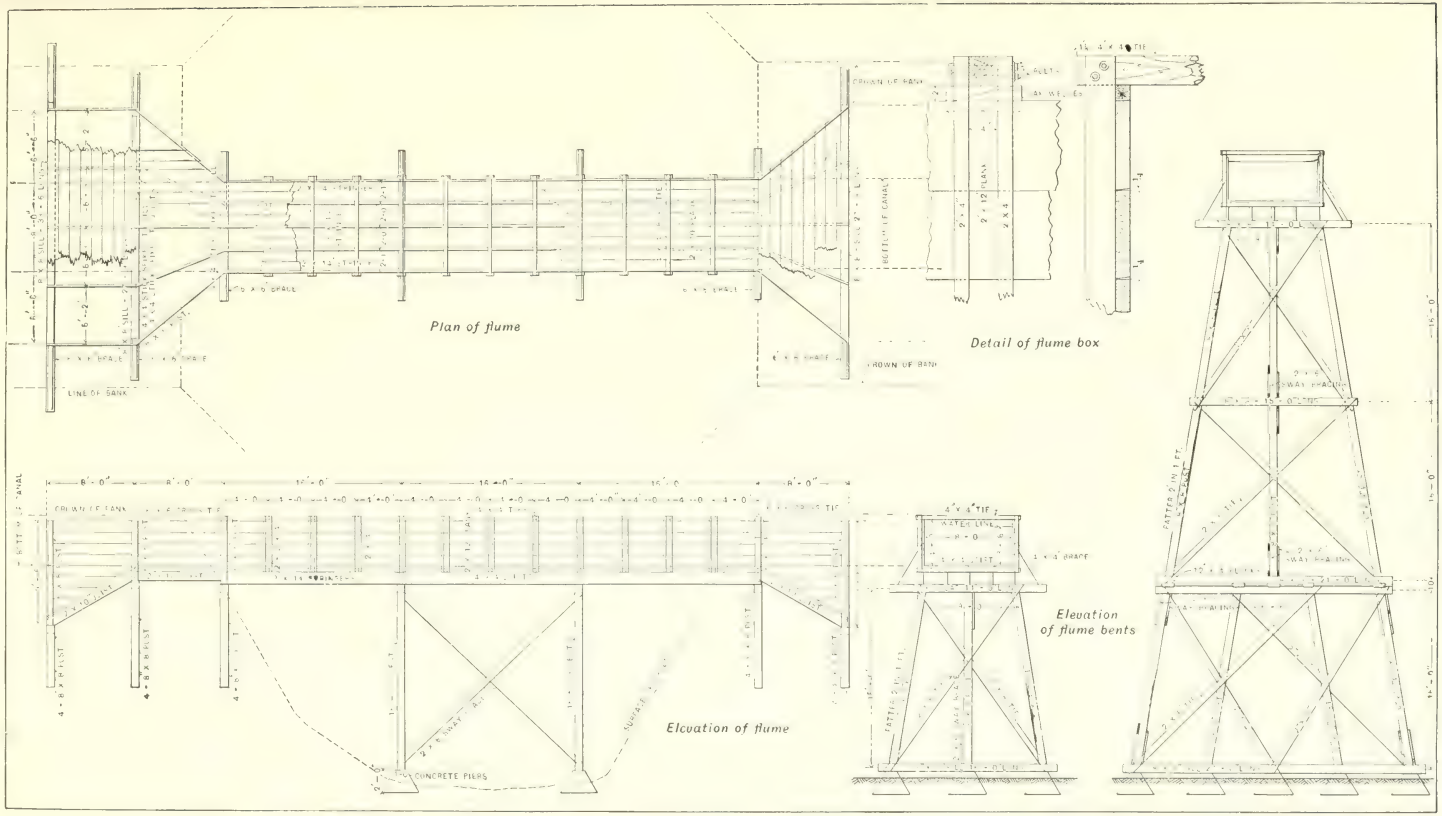
Constituent.	No. 1.	No. 2.	No. 4.	No. 6.	No. 7.	No. 8.
Moisture	.....	2.80	11.25	20.10	13.40	.....
Silica	.....	50.60	55.70	51.00	51.90	67.90
Alumina and ferric oxide	0.20	15.80	20.50	16.70	23.70	18.00
Magnesia	.60	4.072	.....	4.576	.97	.972
Calcium carbonate	95.80	16.60	11.80	6.048	10.90	.00
Insoluble residue	3.30	.....	.....	.....	.....	.....
Total	99.90	89.872	99.25	98.424	100.87	86.872

No. 1. Limestone near dam site; very abundant and convenient.
No. 2. Calcareous shale near dam site; ledge 1 foot thick; expensive to quarry.
No. 3. Shale near dam site; ledge 4 inches thick; expensive to quarry.
No. 4. Clay 1 mile from dam site; abundant.
No. 5. Shale near dam site; ledge 3 inches thick; expensive to quarry.
No. 6. Clay from Sallie May Canyon, 8 miles from dam site.
No. 7. Clay from hills, 3 miles north of dam site; very abundant.
No. 8. Shale from canyon below dam site; ledge 2 feet thick.

The shales, and especially samples 3 and 5, being expensive to quarry and grind, were intended for use only in case the clays should, upon analysis, prove to be unsuitable for the purpose intended.

Everything considered, samples 1 and 7 appeared to be the most favorable for the purpose, and accordingly a quantity of No. 7 and No. 1 were shipped to Colton for an experimental burn. The following is quoted from Mr. Duryee's report:

The clay and limestone were ground separately and then mixed in the proportions of 6.18 pounds limestone and 2.25 pounds clay, making a raw mixture that



DETAILS OF FLUME CONSTRUCTION.

tested 43 per cent lime. As the limestone was very hard and therefore more difficult to make into cement than a softer material, fluorspar to the amount of 1½ ounces, or 1 per cent, was added. The materials were also ground quite fine, but no finer than is the practice in some cement works, viz:

	Per cent.
Passed a sieve of 50 meshes to the linear inch	99.9
Passed a sieve of 100 meshes to the linear inch	99.75
Passed a sieve of 200 meshes to the linear inch	71.75

The raw mixture was made into briquets, and these, after being dried, were burned in a gasoline furnace. They burned to a good hard clinker of a good color, which yielded a cement of good color.

Analysis of the cement.

Lime	63.56
Alumina and ferric oxide	10.40
Silica	22.85
Magnesia	.71

Alkalies not determined.

Tensile tests of the neat cement briquets.

	Pounds per square inch.
7 days (1 day in air, 6 in water)	410
14 days (1 day in air, then in water till broken)	690
28 days (1 day in air, then in water till broken)	775

Chemical analyses of Nos. 1 and 7 were also made in the laboratory of the Geological Survey, to test the uniformity of the deposits. These samples differ slightly from the samples sent to Mr. Duryee, but still are eminently suitable for the purpose. The following are the results found in the Survey laboratory:

Analysis of limestone from Salt River, Arizona.

CaO	55.56
MgO	.10
Fe_2O_3 and Al_2O_3	.20
SiO_2	.51
CO_2 (cal)	43.77
Total	100.14

Analysis of clay No. 7, from Salt River, Arizona.

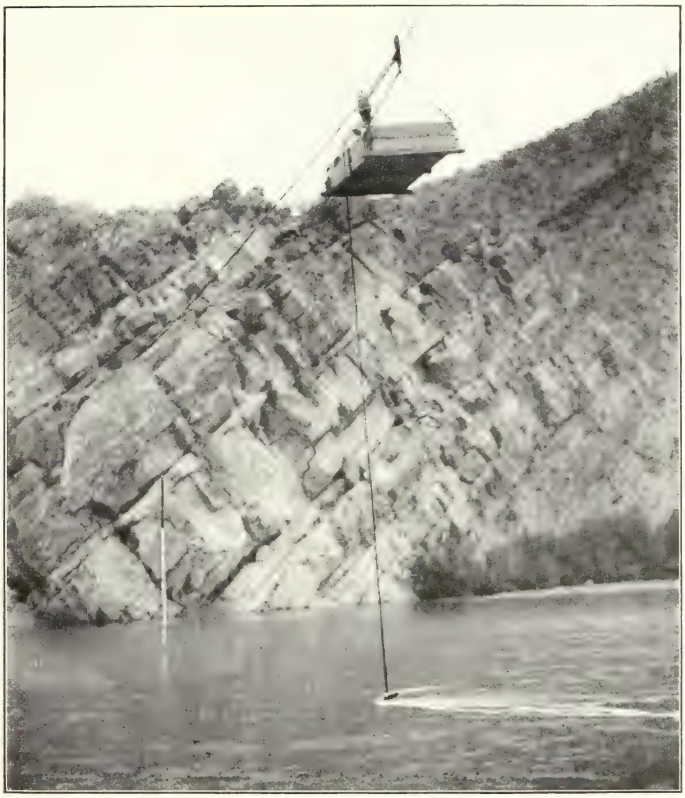
Chlorine	.20
Silica	50.51
Fe_2O_3	5.03
Al_2O_3 and P_2O_5	14.63
TiO_2	.66
MnO	.03
CaO	6.77
MgO	3.00
K_2O	3.06
Na_2O	2.18
Loss at red heat	13.30
Total	99.37

Altogether these results are very gratifying, and prove beyond question the existence of convenient and abundant materials from which cement can be made. The greatest difficulty is the scarcity of fuel. There is considerable wood in the reservoir site, mainly cottonwood and mesquite, which it will be desirable to clear out of the reservoir in any event. Wood is not suitable for burning cement clinker by modern methods, but if made into charcoal and then ground to powder would answer, or oil may be imported for the purpose from California. A large amount of power is required for grinding the rock and the clinker, and a still larger amount will be necessary in the construction of the dam, for excavating to foundation, quarrying and handling the rock, mixing and handling mortar, etc. If steam power were used for all these purposes the small amount of wood at hand would soon be exhausted, and it would be necessary to haul wood a long distance, or to import coal, either of which would be very expensive. Water power can be developed by diverting water from Salt River above the reservoir site, carrying it in a canal above the proposed lake and dropping it through a penstock just below the dam. By such means an ample supply of power can be obtained, available through the construction period and afterwards also, if desired. The chief expense attached to this development will be the construction of the canal for conveying water from the diversion site to the dam site. But as the power will be valuable for other purposes its cost is not entirely chargeable to the dam, and everything considered, this is by far the cheapest manner of obtaining the large amount of power required. This is treated more in detail under the proper heading, page 45.

The estimated cost of the cement plant, with modern machinery capable of producing 300 barrels per day, as furnished by Mr. E. A. Duryee, is as follows:

Approximate cost of a rotary process 2-kiln Portland cement plant of a daily capacity of 300 barrels.

Crusher	$2,000
Mill for disintegrating clay	500
Rotary clay dryer	1,500
Elevators and conveyors for raw materials	1,000
Storage bins for raw materials	1,000
Mills for grinding raw materials	10,000
Two rotary kiln-linings and stacks	15,000
Mills for grinding cement	10,000
300-horsepower electric motors and step-down transformers	9,000
Conveyors and elevators for cement	1,500
Cost of grading and erecting machinery	10,000
Shafting and pulleys, belts, and setting up same	5,000
Buildings and bins for cement	10,000
Office, laboratory, and equipment of same	1,500
Freight	10,000
Plans, specifications, and superintendence	3,000
Total	91,000



A. GAGING STATION ON SALT RIVER, HEAD OF CANYON, BELOW MOUTH OF TONTO CREEK.

B. VIEW UP TONTO CREEK FROM THE GORGE.

With such a mill, and using charcoal for burning cement, the cost of manufacture would be approximately as follows, allowing for power only the proportion necessary for maintaining and operating the electric plant provided:

Cost per barrel of making cement at Salt River dam site, Tonto Basin.

Labor and superintendence	$0.70
Raw materials	.30
Fuel for burning	.90
Power (maintenance and operation only)	.05
Repairs and sundries	.05
Total	2.00

ROADS AND BRIDGES.

The road from Globe to Payson passes through the reservoir almost its entire length. In case of the construction of the dam this road would be submerged, and it will be necessary to provide a new one around the reservoir. If it were deflected to the east it would be thrown into exceedingly rough mountain country, where the construction would be very expensive and the road beset by heavy grades. By passing to the west of the reservoir it would be necessary to use the dam as a viaduct and to build bridges across the spillways. There would not be a great amount of road construction, and this plan would be far cheaper and furnish a much better road than could be built east of the reservoir. The road to the dam site would be necessary in the construction of the dam, and some sort of passageway over the spillways would be necessary in operating the gates.

In view of the contemplated manufacture of cement near the dam and the high cost of steel delivered at the site, it has been decided to build the bridges of the Melan arch type—that is, a light steel skeleton embedded in concrete. This will be about as cheap and far more substantial and permanent than a steel bridge, and more in keeping with the massive and permanent character of the dam. Each bridge is designed to abut at one end on the dam and the other end on the solid rock of the hill, and will have one pier. The spans of each bridge will be 110 feet and 75 feet in the clear. The general design is shown in Pl. XX. They are both similar to bridges that have been in successful use for years and involve no new or untried features.

DAMAGES.

The surveys show about 740 acres of cultivated land that will be submerged by the reservoir. The improvements on these lands consist mainly of small frame or adobe houses, fences, and irrigation ditches. It is thought that an average value of $50 per acre for these lands should be ample to include all improvements. About 4,400 acres of unimproved land is also in private hands, and has little or no value. Allowing $1.25 per acre for such lands, we have a total for damages of $42,500.

The balance of the reservoir site—about 9,000 acres—is public land, the control of which is in litigation, and will not be included in this estimate.

COST.

The following estimates are based upon the data at hand in April, 1902, and are subject to modification:

Estimated cost of Salt River storage dam.

[247 feet above foundation; 190 feet available storage. Capacity, 840,000 acre-feet.]

257,420 cubic yards rubble masonry, exclusive of power and cement, at $3.50 a yard	$900,970
Cement plant	91,000
Power plant, house, and canal	188,360
Manufacture of 150,000 barrels Portland cement, at $2 a barrel	300,000
Excavation of foundation and river diversion	50,000
Outlet tunnels and lining	31,450
Gates and machinery	11,600
Outlet towers, shafts, and houses	9,000
Viaducts across spillways	26,000
Roads	15,000
Engineering and contingencies, 15 per cent	243,507
Total cost of structures	1,866,887
Damage to private lands	42,500
	1,908,387

Cost per acre-foot, $2.27.

The cost of dam 20 feet lower, storing 600,000 acre-feet, would be practically the same for all items except the masonry and cement, which would be about 20 per cent less, making the total cost about $1,680,000, or $2.75 per acre-foot capacity.

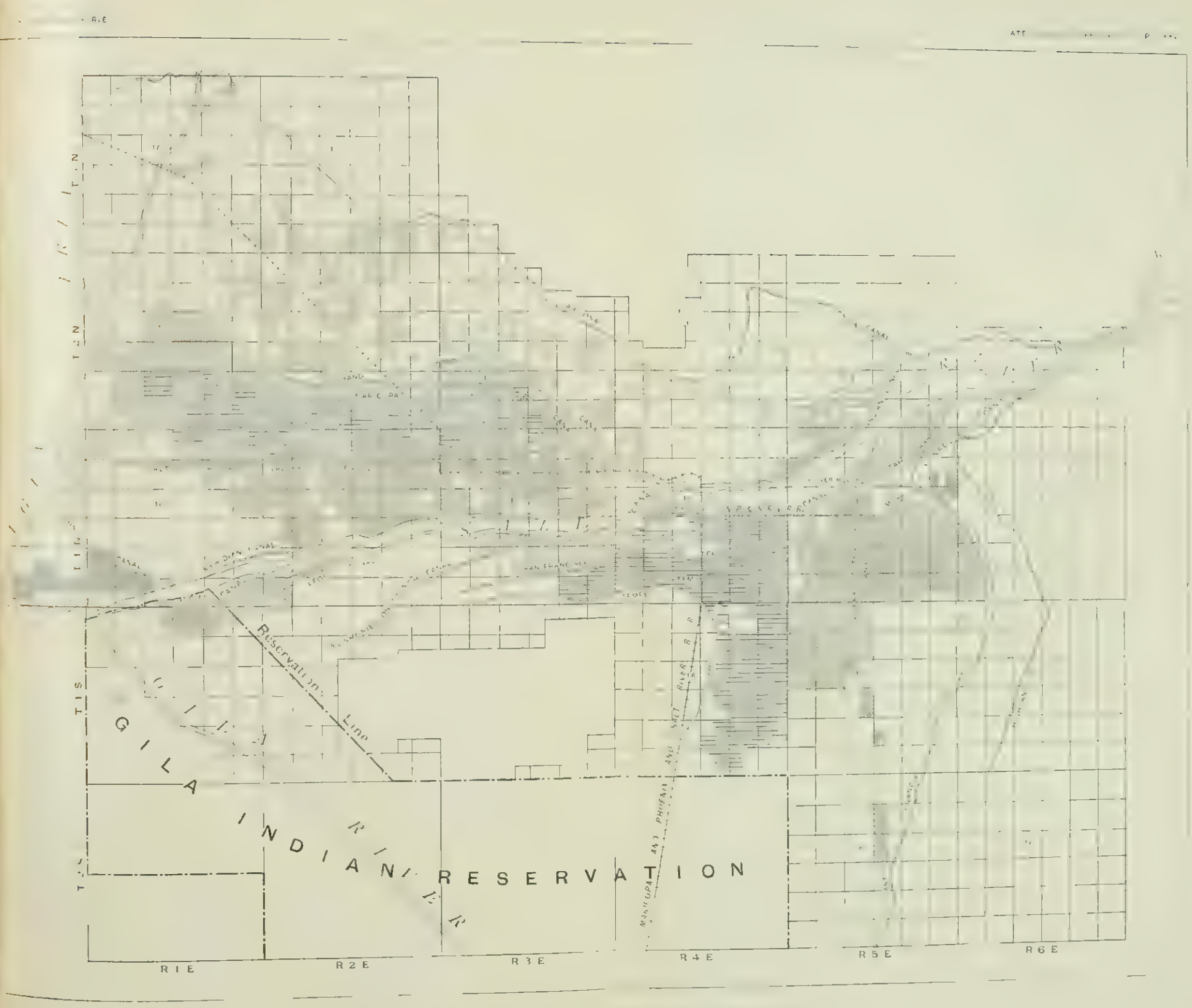
ACKNOWLEDGMENTS.

Generous assistance and valuable suggestions relative to the studies of the problems discussed in this report have been received from numerous sources.

Especial mention is due to the work of Mr. C. R. Olberg, who as principal assistant has performed the major portion of the voluminous computations and most of the detailed designing connected with the structures adopted for the Salt River reservoir, and has displayed in this work a commendable degree of skill and conscientious care.

Thanks are due to Mr. W. H. Code for the benefit of his valuable experience in pumping water by electric power for irrigation and for his advice regarding the relative quantities of water consumed in the various months of the year.

Acknowledgments are also due to Mr. F. P. Trott for valuable information concerning the water supply and for surveys on the McDowell reservoir site, the latter being made at considerable expense to him and freely furnished in the public interest.



MAP OF SALT RIVER VALLEY SHOWING CANALS AND IRRIGATED LANDS

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WATER RESOURCES

OF THE

STATE OF COLORADO

BY

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LETTER OF TRANSMITTAL

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., July 10, 1902.

SIR: I have the honor to transmit herewith, for publication as Water-Supply and Irrigation Paper No. 74, a manuscript by Mr. A. L. Fellows on the water resources of the State of Colorado.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF COLORADO.

By A. L. Fellows.

INTRODUCTION.

The State of Colorado, located as it is in the midst of the Rocky Mountains, the crest of the continent crossing it from north to south, and comprising as it does a vast variety of physical conditions, varying from those of the highest mountain regions, where vegetation ceases to flourish, to plains where fruits almost semitropical may be raised, furnishes a diversity of problems connected with the disposition of its water supply unequaled in number and difficulty, perhaps, by those arising in any other State in the Union. The snows of winter, falling upon the continental divide, may furnish the moisture by which the herbage and trees of the mountains are watered, and the waters from these heights, collected in rivulets and streams, may supply the motive power for operating the stamp mills for the mines of the State, or may develop electric power that may be transmitted for running factories, or may be used for sifting out the particles of gold in the placers along the streams of both the Pacific and the Atlantic watersheds. Again the brooks and creeks, collected into larger streams or rivers, enter the broad plains of the eastern half of the State or the canyon and mesa country of the western half, and furnish the lifeblood of vast irrigated tracts, where crops of the most diverse kinds may be raised for the sustenance of countless families, and thus become the assets upon which agricultural communities may draw, whether they are dependent upon wheat raising, sugar factories, potatoes for the Eastern market, alfalfa for feeding lambs and sheep,[a] or any other of the numerous forms of agricultural industry practiced in Colorado. Its water supply therefore becomes of the utmost importance to the State, and it is with the hope that the compilation of all figures readily obtainable bearing upon the subject may prove of interest and value to the people, not only of Colorado, but of States similarly situated, that the preparation of this paper is undertaken.

[a] Colorado Agricultural College Bulletins.

SOURCES OF INFORMATION.

For a period of about sixteen years the measurement of streams has been carried on more or less systematically in the State both by the Hydrographic Division of the United States Geological Survey and by the State engineer's office, working at times in cooperation and at times separately, but always with the same end in view—that of throwing as much light as possible on the discharge of the streams and of determining the feasibility of storing water in available reservoirs whenever the need for such storage should become apparent. The discharge measurements given in this paper are compiled from the records of these offices. When the different records are found to be conflicting, as they sometimes appear to be, credence is given, after careful consultation with those most intimately acquainted with the existing conditions, to the one appearing to be the most likely to be correct.

The records of the United States Geological Survey and of the State engineer's office are the two principal sources from which the following tables are compiled, but information has also been obtained from engineers located in different parts of the State wherever it was possible, and in such cases due credit is given.

The drainage areas given are computed from the General Land Office maps by means of the planimeter, these being the figures accepted in the reports of the United States Geological Survey. The descriptions of streams and drainage basins and of reservoir sites are compiled largely from bulletins, irrigation papers, and reports previously published, but to a considerable extent also from personal examination and knowledge. In the computations use has been made of the tables given in Bulletin of the U. S. Geological Survey No. 140, pages 14 to 32, and Water-Supply and Irrigation Paper No. 27, page 96, to which readers are referred for directions concerning the use of meter and computations of discharge.[a] In a paper of the size to which this must be limited, it is, of course, impossible to give complete results of discharge measurements and of daily gage readings. It has been thought best, therefore, to limit the data given for each station to a table of gagings and to a general table giving the average flow for each month, the average for each year, the maximum and minimum flow for each year, and the most important data connected with the stream measured. With each table is given a brief description of the station at which the results were obtained, showing the value of these results, the prevailing conditions, and the sources from which the information was derived. References are made, wherever

[a] See also, for methods of making measurements, Annual Reports U. S. Geol. Survey: Tenth, Part II, pp. 78 to 86; Eleventh, Part II, pp. 2 to 22; Fourteenth, Part II, pp. 96 to 100; Nineteenth, Part IV, pp. 18 to 31; Twentieth, Part IV, pp. 20 to 22. Also, State Engineers' Biennial Reports: Second, pp. 5 to 9; Third, p. 5; Fourth, pp. 59 to 88; Fifth, pp. 346 to 349; Sixth, p. 8; Seventh, pp. 196 to 217; and Irrigation Bulletin No. 1.

they are deemed desirable, to the reports or water-supply papers of the United States Geological Survey that give more detailed information, so that any reader looking up discharge data upon any particular stream may be assisted in his search for the most complete information.[a] For greater convenience of reference the following table, showing the publications most fully covering the hydrographic work for each year from 1883 to 1900 inclusive, is given below:

Reports of the State engineers of Colorado.

Second Biennial Report, 1883–1884.
Third Biennial Report, 1885–1886.
Fourth Biennial Report, Parts I and II, 1887–1888.
Fifth Biennial Report, Parts I and II, 1889–1890.
Sixth Biennial Report, 1891–1892.
Seventh Biennial Report, Parts I and II, 1893–1894.
Eighth Biennial Report, 1895–1896.
Ninth Biennial Report, 1897–1898.
Tenth Biennial Report, 1899–1900.

Publications of the United States Geological Survey.

Tenth Annual Report, Part II, 1888.
Eleventh Annual Report, Part II, 1889.
Twelfth Annual Report, Part II, 1890.
Thirteenth Annual Report, Part III, 1891.
Fourteenth Annual Report, Part II, 1892.
Bulletin No. 131, Report of Progress of the Division of Hydrography, 1893.
Bulletin No. 131, Report of Progress of the Division of Hydrography; also Sixteenth Annual Report, Part II, 1894.
Bulletin No. 140, Report of Progress of the Division of Hydrography for the Calendar Year 1895; also Seventeenth Annual Report, Part II, 1895.
Eighteenth Annual Report, Part IV; also Water-Supply and Irrigation Paper No. 11, 1896.
Nineteenth Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 15 and 16, 1897.
Twentieth Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 27 and 28, 1898.
Twenty-first Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 35, 36, 37, 38, and 39, 1899.
Twenty-second Annual Report, Part IV; also Water-Supply and Irrigation Papers Nos. 47, 48, 49, 50, 51, and 52, 1900.

In the compilation of this paper assistance has been given by many different persons and corporations interested in the use of water, and to all these thanks are extended. The attempt has been made to give proper credit in all cases where such assistance has been furnished. The illustrations are selected from photographs made under the auspices of the Survey, and from those furnished by parties assisting in the preparation of this paper.

[a] It is not intended that the references to publications relating to this subject shall form a complete bibliography, but an attempt is made to assist the reader in finding some of the most easily obtainable information on the subjects considered.

VALUE OF SUPPLY.

The mining industries of Colorado depend very largely upon the water supply of the mountain region for the development of power by which stamp mills and sampling works may be operated, and the mining towns are dependent upon electric-light and power plants operated by water; and the mills and factories of the State are, to a greater and greater extent, being run by the same means; further, the cultivation of between two and three millions of acres of land is made possible by water used in irrigation; and when it is seen that this water supply is so limited that the normal flow of very many of the streams is entirely exhausted and that already recourse is being had to storage in reservoirs, built to conserve, for use in seasons of low water, floodwater that would otherwise go to waste, it will then be evident that its water supply is of the greatest moment to the State. This fact has been recognized by the people themselves ever since the State was formed, and a complicated system of laws has been built up controlling the water and its distribution among consumers. This subject has already been fully treated in a number of different bulletins and papers, among which are Water-Supply and Irrigation Paper No. 9, U. S. Geological Survey, and Bulletins Nos. 58 and 60 of the United States Department of Agriculture, as well as the Irrigation Laws of Colorado, as compiled and furnished by the State engineer's office, so that nothing more than a brief discussion as to the ownership of water by Colorado is necessary at this time.

By the State constitution the water is declared the property of the State, and as such is to be distributed and used in accordance with its occurrence and availability. The entire system of State laws distributing the water among consumers is based upon this plan, the State engineer being made, next to the courts, the head of the department having immediate supervision of the subject, and being the final authority on questions relating to the use of water, subject to appeal to the courts. Next to him and his deputies are the superintendents of the various irrigation divisions, of which there are 6, each of them comprising lands drained by one of the six principal streams of the State; namely, the South Platte, the Arkansas, the Rio Grande, the San Juan, the Grand, and the Green rivers. Each of these divisions in turn is divided into water districts, each one comprising one or more of the tributaries of the various large streams, or parts of the main streams themselves, each district, of which there are 69 in the State, being under the supervision of a water commissioner, whose duty it is to regulate the use of the water under his immediate jurisdiction, appeals being possible from the commissioner to the superintendent, from the superintendent to the State engineer, and from the State engineer to the courts. This partition of the State into divi-

sions and districts will be treated more fully later, so that further description is unnecessary at present.

The uses of the water are so numerous and varied that the administration of the laws relating to water is very difficult. In Colorado the riparian doctrine does not obtain, so that this complication is removed — at least unless decisions should be rendered in the United States courts acknowledging such rights as belonging to the States into which the streams flowing out of Colorado run—but the complications are numerous enough as it is. The supply of water is so limited compared with the demands for it that early rights or priorities become of the utmost importance. The principal uses to which the water may be put may be classified in the order of importance as domestic use, irrigation, mining, and milling. The use of the normal flow of the streams is considered as of first importance, the use of stored water being a matter for secondary consideration.

The order in which water would naturally be used, however, is different, and, leaving out of consideration entirely for the present the fact that priority of use may determine right to use, it is obvious that the physical nature of the State has an important bearing upon the problems of use. The mines being situated in the mountains, and the natural conditions being usually such that the clearest and best water is found at the higher altitudes, it is evident that, other things being equal, water for domestic use and for mining would be demanded at the highest available points upon each stream. After the water begins to find its way into canyons and over waterfalls—in other words, when it is discharging from the mountains into the plains—the conditions evidently become more favorable for the development of power, the fall of the streams being rapid, and the quantities being sufficient for such use. Again, after the water debouches from the mountainous area and enters the plains, it is evident that irrigation may be practiced upon a broader scale, so that the order of use upon a stream would naturally be domestic use, mining, milling, and water power, and, finally, irrigation.

The brief discussion of the uses to which the water may be put in Colorado sufficiently demonstrates the importance of the subject. It is not within the province of this paper to treat of the administration of the laws, or to discuss the subject of priorities. Its intention is simply to show, so far as possible, how much water is available for use in some of the streams of the State, and to indicate briefly, by examples, something of what is being done in harnessing this, one of the greatest dynamics of nature, for the use of man. At the same time an effort will be made to show the necessity for the storage of the waters that now go to waste in the winter seasons and at flood stages, in order that there may be the most economical and thorough use of this great resource. That the period when storage is demanded

is already at hand is clear to all students of the hydrography of the State, for the normal flow of the majority of the streams is already utilized and exhausted. It is not now proposed to discuss the most economical use of water—that water is used in Colorado most extravagantly and in ways that would not be tolerated in a country more advanced in scientific irrigation is beyond question—but simply to consider the present use of water and endeavor to devise methods by which this use may be extended, so far as possible, under existing conditions. Necessity will compel more economical use in the future; but the present most urgent need is that the water which now goes to waste and is of no service to man shall be conserved so as to be available for beneficial use. Such streams as the South Platte, the Cache la Poudre, the Arkansas and its tributaries, the Rio Grande, and numerous other streams, furnish normally an insufficient supply for present needs, but if the flow could be equalized by the storage of water in reservoirs the irrigated area in Colorado might be greatly extended. The importance of this fact is already felt, and in many places, as upon the Big Thompson, the Cache la Poudre, and the Arkansas, considerable water is already being stored, to the great benefit of the people within the irrigable territory lying below the reservoirs.

RUN-OFF.

The physical conditions affecting the run-off in the State of Colorado are so various that it is impossible to formulate an even approximately correct rule as to the percentage of the rainfall carried from the drainage area into the streams.[a] In case of a violent storm of the nature of a cloud-burst in a rocky, mountainous district, as much as 75 or 80 per cent of the precipitation may be collected into the nearest streams; it will, however, be largely taken up by percolation into the soil before it has run a very great distance. On the other hand, a great amount of water falling gently upon a sandy plain may be entirely absorbed by the soil and may evaporate before any water whatsoever has run off. Computations of the percentage of run-off are often misleading, also, from the fact that water is being constantly taken out of the various streams for irrigation. For example, no accurate estimate could be made from the discharge of the Arkansas River at Rocky-ford as to the percentage of run-off from the drainage area above, as water is constantly being taken out for reservoirs and for direct irrigation, and the amount so taken can hardly be calculated unless a complete record is made of the intake of each canal, whether large or small, along the Arkansas and all its tributaries. Where there are no irrigating canals or ditches along a stream it is comparatively easy to determine the percentage of the total precipitation contained in the

[a] See also Biennial Reports of the State Engineer: Second, pp. 10–18; Fourth, pp. 17–23.

run-off at a given point; but when water is diverted from a stream in such quantities that only a comparatively small portion returns, the determination of run-off becomes difficult. Where gaging stations are located at the mouths of canyons, however, above which there is little, if any, diversion, the percentage may be determined with reasonable accuracy, although even then it is difficult to find points on any of the streams above all diversion for irrigation and yet far enough down to be of great use in the determination of run-off. For example, on the St. Vrain, the discharge at the gaging station at Lyons will not give correctly the run-off of the drainage basin above, for the reason that meadows are being irrigated at places far above the gaging station. The Boulder, again, is at times losing water that is being stored in reservoirs high up in the basin, and such is the case with the majority of the other streams. For these reasons no attempt has been made to determine what relation the total precipitation bears to the run-off. Readers interested in these computations are referred to Part IV of the Twentieth Annual Report of the United States Geological Survey. That the run-off does depend upon the precipitation, however, is self-evident, and for this reason a table giving the precipitation at various points in the State, beginning with the year 1896, is furnished. A comparison of the depth of the run-off in inches, as given in the tables of discharge, with the precipitation in inches for a given year, will give an approximately correct idea of the amount of water flowing in a stream at any given point.[a]

Normal temperature and precipitation at stations in Colorado.

[Compiled from the records of the Office of the U. S. Weather Bureau, at Denver, Colo. F. H. Brandenburg, section director.]

Station.	County.	Elevation.	Length of record.	Normal temperature.	Precipitation (in inches).					
					1896.	1897.	1898.	1899.	1900.	Normal to 1899, inclusive.
South Platte drainage:		*Feet.*	*Years.*	°*F.*						
Boxelder	Larimer	6,950	10	.....	17.83	21.42	16.34	14.42	17.93	16.46
Laporte	do	5,069	10	.....	15.49	17.72	13.63	13.34	20.06	14.37
Fort Collins	do	4,995	20	46.8	15.76	15.24	11.03	16.19	19.21	13.86
Greeley	Weld	4,637	11	47.5	13.52	16.09	(b)	10.79	11.51	11.83
Moraine	Larimer	7,900	11	40.6	17.28	18.87	16.86	16.58	16.72	17.56
Dumont	Clear Creek	8,000	10	.....	15.91	20.82	17.16	18.19	19.54	18.59
Denver	Arapahoe	5,291	29	49.8	11.84	15.37	12.98	9.33	15.29	14.15
Castlerock	Douglas	6,220	10	46.3	20.44	(b)	(b)	14.70	14.70	18.59
Hamps	Elbert	5,500	8	45.8	12.78	(b)	12.57	12.67	21.17	12.26

[a] See Reports of the Weather Bureau; also U. S. Geological Survey Reports: Tenth, Part II, pp. 13–14; Seventh, Part II, pp. 23, 25, 205, 214, 251, and 281; Twelfth, Part II, pp. 226, 230, 231, and 245; Thirteenth, Part III, pp. 25, 28, and 153; Fourteenth, Part II, pp. 150–152; and Biennial Reports of the State Engineers of Colorado: Second, pp. 14–17; and Fifth, Part I, p. 534. Also, Report on Agriculture and Irrigation, Eleventh Census, by F. H. Newell, p. 91.

[b] Record incomplete.

Normal temperature and precipitation at stations in Colorado—Continued.

Station.	County.	Elevation.	Length of record.	Normal temperature.	Precipitation (in inches). 1896.	1897.	1898.	1899.	1900.	Normal to 1899, inclusive.
		Feet.	*Years.*	° *F.*						
Kansas drainage:										
Leroy	Logan	4,380	12	48.1	14.18	18.48	14.95	13.22	14.74	15.10
Yuma	Yuma	4,128	10	.....	15.84	18.30	20.39	14.61	17.98	16.63
Wray	do	3,512	7	.....	16.68	20.19	18.71	10.74	18.24	15.13
Cope	Arapahoe	.....	9	50.1	(a)	(a)	28.48	(a)	21.47	18.42
Fox	do	.....	9	.....	(a)	17.19	20.84	10.06	19.92	15.56
Seibert	Kit Carson	4,705	9	.....	14.42	20.94	18.65	12.62	20.79	14.31
Cheyenne Wells.	Cheyenne	4,259	8	.....	(a)	(a)	18.50	14.01	18.60	15.76
Arkansas drainage:										
Lake Moraine.	El Paso	10,268	7	.....	19.70	30.32	23.14	18.59	33.46	22.55
Gleneyre	do	6,500	9	46.7	15.53	(a)	(a)	(a)	19.34	13.98
Colorado Springs.	do	6,098	21	.....	13.94	(a)	(a)	8.81	13.64	14.13
Leadville	Lake	10,185	8	.....	(a)	15.51	12.27	19.86	13.50	14.21
Twin Lakes.	do	9,200	7	.....	(a)	(a)	(a)	(a)	13.76	15.35
Canyon	Fremont	5,363	12	.....	11.96	11.13	11.45	9.80	14.34	11.70
Pueblo	Pueblo	4,734	12	.....	10.81	12.71	10.85	13.05	13.37	11.53
Rockyford	Otero	4,177	12	.....	9.74	(a)	16.04	18.68	15.60	13.52
Las Animas	Bent	3,892	33	.....	11.81	10.89	15.63	12.11	15.48	11.19
Lamar	Prowers	3,592	11	.....	(a)	15.10	17.84	19.64	19.64	15.17
Westcliffe	Custer	7,864	8	.....	13.27	(a)	16.88	12.81	16.31	17.29
Clear View	Las Animas	9,500	11	.....	24.00	31.76	27.31	18.49	23.08	24.23
Hoehne	do	5,721	9	.....	16.05	11.80	14.07	12.36	13.30	13.92
Springfield	Baca	4,400	9	.....	(a)	(a)	20.75	12.78	22.68	18.36
Vilas	do	4,158	10	.....	(a)	(a)	(a)	15.48	19.66	13.74
Rio Grande drainage:										
Saguache	Saguache	7,740	10	42.0	(a)	8.84	8.06	5.96	6.25	7.52
San Luis	Costilla	7,596	10	42.3	12.31	13.93	14.20	10.04	10.16	13.06
San Juan drainage:										
Durango	La Plata	6,534	8	47.3	(a)	24.93	16.27	14.49	9.86	17.98
Mancos	Montezuma	7,008	2	45.6	(a)	(a)	(a)	12.35	12.44	(a)
Grand drainage:										
Breckenridge	Summit	9,524	12	33.2	24.03	24.49	16.29	29.41	14.62	29.44
Parachute	Garfield	5,105	9	49.8	(a)	(a)	(a)	18.14	7.89	11.37
G. S. ranch	Mesa	5,200	14	52.1	(a)	14.45	8.37	13.17	6.09	11.77
Grand Junction	do	4,608	10	49.2	8.22	11.10	5.45	10.87	3.64	8.89
Cedar Edge	Delta	6,175	9	.....	9.33	15.05	9.48	10.90	9.67	11.89
Delta	do	4,980	12	.....	(a)	11.87	4.72	8.44	5.19	8.78
Antlers	Garfield	5,350	15	.....	(a)	17.92	9.16	15.81	5.82	(a)
Green drainage:										
Meeker	Rio Blanco	6,182	8	.....	16.28	24.30	13.34	20.05	(a)	b16.92
Pagoda	Routt	6,500	9	41.1	17.38	29.13	18.92	24.05	12.32	20.53
Lay	do	6,200	7	.....	14.04	(a)	(a)	(a)	7.60	13.62

a Record incomplete. b Normal to 1898, inclusive.

As has been suggested, the run-off of a mountainous area will differ very considerably from the run-off of an equal area on the plains. A

given amount of precipitation in South Park, for example, will furnish to the same stream a very much greater run-off than the same amount of precipitation on the plains north of Sterling, the more rocky and broken by ravines the territory the greater being the percentage of run-off. The character of the rock formation and the nature of the canyons through which the water flows also have important bearings upon this percentage. Twelve inches of precipitation on the headwaters of the Arkansas will furnish a greater percentage of run-off than the same amount falling on an equal area of the Mesa Verde, in southwestern Colorado, the rock in the former case absorbing little water and the soil being of such nature that the water does not percolate through it to a very great extent, and the rock in the latter case being a soft sandstone and the ravines having sandy beds. For these reasons it is evident that to determine the run-off at any particular point a series of stream measurements must be made, for determinations based solely on the precipitation of a region would be only approximate.

The effect of forests in conserving moisture and in rendering the discharge of the streams more equal throughout the year is thoroughly demonstrated and generally admitted.[a] Whether or not the presence of forests increases precipitation in a given territory is of little importance compared with the question of the extent to which the forest keeps back the floods of the spring and early summer for later use. An examination of discharge tables obtained at stations that have been long maintained will show that the high-water stage is becoming each year earlier and of shorter duration. It is self-evident that anything that will tend to equalize the flow of streams throughout the year has an important bearing on the use of water. A given stream may be adequate to irrigate all the cultivable land along its borders if its water can be properly distributed throughout the irrigating season. When, however, as is the case upon many streams, the water runs off rapidly in May and in the early part of June, it will happen that while there is a great surplus of running water during the early part of the year, yet the stream may be nearly dry at a time when a great deal of water is needed for irrigation. This is the case, for example, upon the Mancos River, in the southwestern part of the State, in which during the month of May enough water goes to waste to furnish all the adjacent irrigable land with a sufficient supply if it could be properly stored.

In studying this question one should not fall into the error of supposing that in order to make the most economical and satisfactory use of the water the supply should be equal throughout the summer

[a] See Fifth Biennial Report of the State Engineer of Colorado, p. 43; Bulletin No. 55, Colorado Agricultural Experiment Station; Twentieth Annual Report, U. S. Geological Survey, Part V, and reports of the Forestry Division of the Department of Agriculture.

season. Usually more water is needed in the latter part of May and in early June than would be required in any other month; that is to say, the duty of water—the area of land that may be served by a given quantity of water—is least in May and June, and increases rapidly toward the end of the season, so that it would be a mistake to suppose that if, for example, 100 cubic feet per second were required for a given area at the time when most water was needed, that provision must also be made for a flow of 100 cubic feet per second regularly throughout the remainder of the so-called irrigation season. Such a run of water at a time when little of it was being used could not do otherwise than cause great damage by washing away the soil and making swamps of the lowlands. The amount of water used at various seasons will depend largely on the kind of crops raised and on the nature of the season. This phase of the irrigation problem is being studied by the Agricultural Department, and a number of bulletins and papers have already been written on this subject,[a] as well as on loss of water by seepage and evaporation.[b] It is therefore sufficient here to call attention to the facts that when the run-off is the greatest the use of water is also generally the greatest, and that the amount of water required diminishes somewhat as the normal supply itself diminishes, only less rapidly; so that the most economical use of the water of a given stream is obtained when all the land along that stream is cultivated that can be supplied with water directly from the stream itself for about two months of the year, the balance of the supply being stored from waters that would otherwise have gone to waste during the high stages, and the amount of land cultivated being so regulated that practically all of the water is used.

On streams where there is no flow normally, as is usually the case with the streams of the plains, the supply consisting almost entirely of a discharge lasting a few hours only during and after storms, the situation is, of course, different. If all of the water of such streams can be stored in reservoirs, it may be drawn off gradually and used for irrigation. The chief difficulties in such cases are that the water usually comes down in great quantities very heavily laden with silt, so that it is almost impracticable to construct canals that will carry it without either erosion or filling, and that reservoirs constructed in the beds of such streams usually fill with sediment very quickly. Sometimes, however, a stream is so fortunate in its situation and regimen

[a] Bulletins of the U. S. Department of Agriculture, Office of Experiment Stations, Nos. 73, 81, and 86, and Bulletin No. 22 of the Agricultural Experiment Station at Fort Collins, Colo., and U. S. Geological Survey Annual Reports as follows (see indices of same, under Duty of Water): Tenth, Part II; Eleventh, Part II; Twelfth, Part II; Thirteenth, Part III; and Fifth State Engineer's Report, p. 46; Sixth, p. 67; Seventh, p. 7; Eighth, p. 20; Ninth, pp. 17, 51, and 59. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 95.

[b] Bulletins Nos. 45 and 48, Agricultural Experiment Station, Fort Collins, Colo., and U. S. Geological Survey Annual Reports as follows (see indices of same, under Evaporation): Eleventh, Part II; Twelfth, Part II; Thirteenth, Part III; Fourteenth, Part II; Twentieth, Part II; also Bulletin No. 140.

that a considerable portion of its water may be drawn away from the channel in which it flows and diverted to some adjacent reservoir site. The chief differences, therefore, between a mountain or perennial stream and one flowing on the plains are that irrigation may be practiced from the first by water taken directly from the stream, while the water from the second must be stored before it can be used, and that the water of one is comparatively clear, while that of the other is inordinately filled with silt.

The storage of surplus water is a great problem in itself. In many localities where there is plenty of water that is going to waste no satisfactory reservoir sites are available; on the other hand, many of the best reservoir sites of the State are in localities where it is difficult to get water to them from the natural streams. Few people, comparatively speaking, realize how large a reservoir must be to supply any considerable amount of land with water for irrigation. Those who have reservoir propositions in view should bear in mind that where land is to be irrigated entirely by means of the water stored in a reservoir it will, making all necessary allowances, take approximately 2 acre-feet—that is, 2 acres covered with water 1 foot deep, or, what amounts to the same thing, 1 acre covered with water 2 feet deep—to irrigate a single acre of land for a season; so that to irrigate 1,000 acres of land would require a reservoir, let us say, covering an area of 100 acres 20 feet deep, if all the water is to be derived from this source and none directly from the stream. This suggestion is made for the reason that persons often recommend the examination of a reservoir site which they say would store water for a whole township, whereas in reality it would furnish little more than enough for stock use for a good-sized cattle ranch. That there are many available reservoir sites, however, throughout the State, is beyond question, and information and data concerning such sites is always gladly received. A few of the more important sites already examined will be mentioned from time to time in this paper.

WINTER DISCHARGE.

In compiling the tables given hereafter the records for the winter months have usually been accepted as furnished by the observers. It is, however, unsafe to trust these records unreservedly, for in nearly all of our mountain streams ice gorges are constantly being formed in winter, changing the velocity of the current and the gage height recorded by the observer without materially changing the discharge of the stream. It is often safer to strike an average between the November flow and the flow of about the middle of March or the first of April following than to trust to the apparent discharge as derived from the observations. For this reason the winter discharge has been

omitted from a number of stations where the figures if given would have been absolutely misleading; they are retained, however, in a few stations, and where any false impression might arise from the figures given, attention is called to that fact in a footnote.

EXPLANATION OF TABLES.

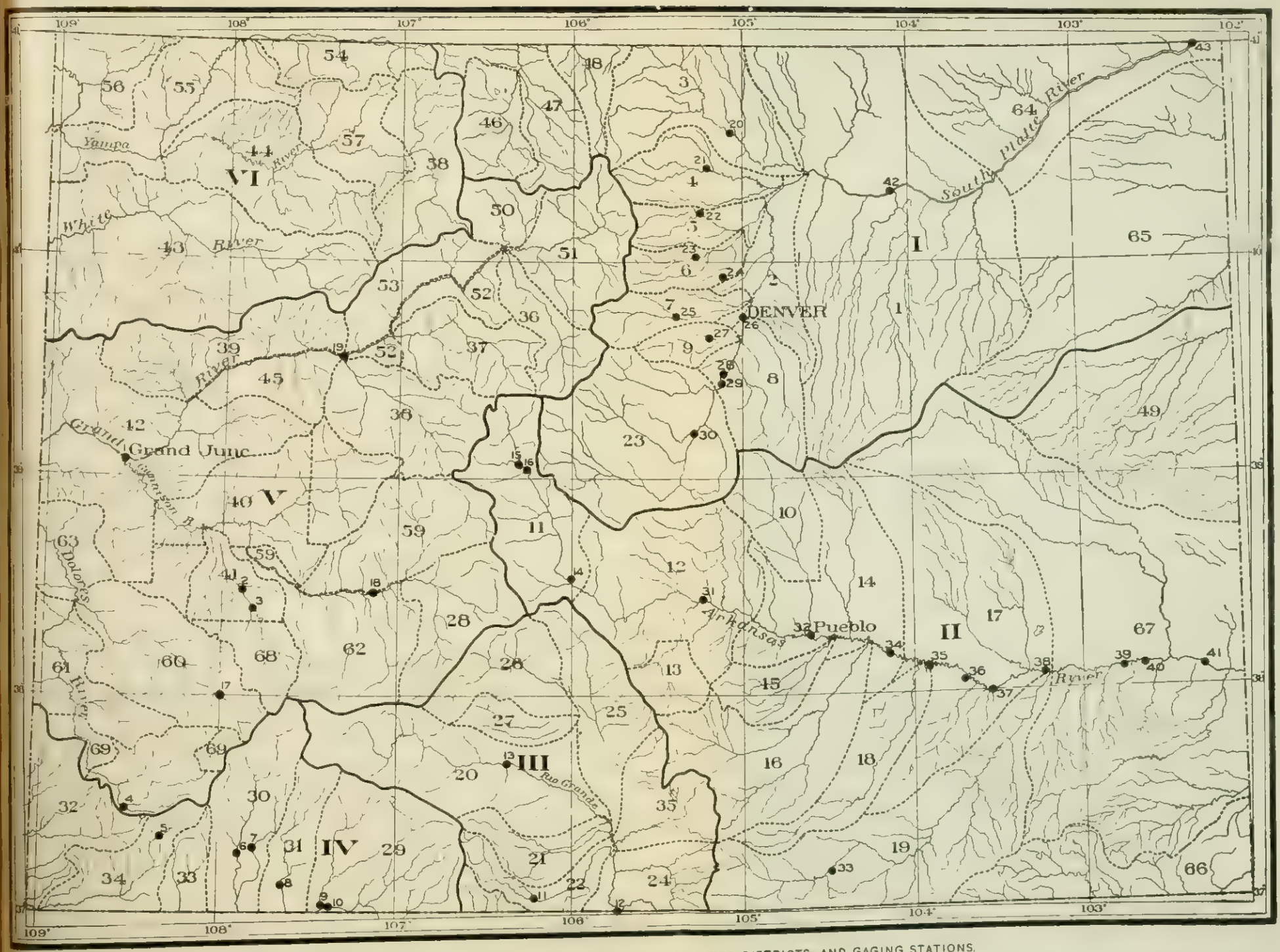
In general the tables given in this paper are summarized from all available data. For stations where records exist for from one to three years only the discharge is given for each year individually, but for stations where records have been maintained for four or more years the average discharge is usually given for each month during which the record was kept and these averages are again averaged, giving a normal discharge for each month as computed for that month of each year during which records were kept, these being again averaged for a normal year or that portion of the year covered by the records. The discharge in second feet per square mile given in the vertical columns in these tables is the amount corresponding to the average flow for the same months or periods, the depth in inches being derived directly from the flow in second feet per square mile and corresponding thereto. The discharge for that portion of each year covered by the record, or for the whole year, as the case may be, is averaged and placed below the record for that year. The number of acre-feet given is in each case the corresponding amount for the period covered. The number of second-feet per square mile is derived from the average flow for the period covered, and the depth of run-off in inches is derived from them, usually for a thirty-day period, but at times for the entire year or for the entire period covered, the variations being mentioned in the accompanying footnote in each case. It is believed that the footnote accompanying each table is sufficient for further explanation of the table.

IRRIGATION SYSTEM.

As has already been mentioned, the State of Colorado is divided into six irrigation divisions, each comprising a considerable portion of the State, drained usually by a single stream and its tributaries, these divisions being in their turn divided into districts (see Pl. I), as will be more fully described later.

The six divisions are as follows: Division No. I, or South Platte River; No. II, or Arkansas River; No. III, or Rio Grande; No. IV, or San Juan River; No. V, or Grand River; No. VI, or Green River; each consisting in general of the territory drained by the stream (with its tributaries) from which the division takes its name.

[a] Bulletins Nos. 48, 60, and 73, Office of Experiment Stations, U. S. Department of Agriculture, Water-Supply and Irrigation Paper No. 9, U. S. Geological Survey, and reports of the State Engineers of Colorado.



MAP OF COLORADO, SHOWING IRRIGATION DIVISIONS WATER DISTRICTS, AND GAGING STATIONS.

Irrigation divisions each drained usually by a single stream and its tributaries, are indicated by roman caps (I–VI) and heavy lines water districts by broken lines and arabic numerals gaging stations by smaller arabic numerals and large dots

SOUTH PLATTE DIVISION.

DRAINAGE.

Division No. I, or South Platte River division,[a] consists of the territory drained by South Platte River and its tributaries, but includes also North Park, drained by the North Platte and its tributaries, in which are located water districts Nos. 46, 47, and 48. Water district No. 65 is also included, which covers the territory within the northern half of the Kansas River Basin in Colorado drained by Frenchman Creek, the North Fork of the Republican, and the Arikaree. The two latter streams, however, in district No. 65, are of little importance, so far as irrigation in Colorado is concerned, as they head too near the eastern border of the State and carry too small amounts of water to be of much value.[b] The country drained by these streams varies in altitude from about 5,000 down to 3,800 feet above sea level. This area is what has been known in the past as the rain-belt country, and for some years there was a general belief that farming could be practiced successfully in that region without irrigation, but such farming has not been found to be profitable, and agriculture in that section hereafter will be generally limited to small tracts that can be irrigated, either directly from the streams or by means of storage. In some cases artesian wells produce a flow sufficient for stock use and for the cultivation of small patches of ground. No gaging stations have been established upon any of these streams.

The streams of North Park are of more importance. District No. 46 consists of the territory drained by the North Platte proper in Colorado as far down as its junction with Middle Fork. No. 47 consists of the territory drained by the Middle Fork and its tributaries and the North Platte below its junction with Middle Fork. No. 48 consists of the drainage basin of the Laramie and its tributaries. The territory comprising North Park is in general a rolling, more or less timbered country, with numerous small streams flowing through it. The principal industry is stock raising, crop raising being limited to hay and grain. Little irrigation is practiced, this being limited principally to hay meadows. On the Laramie, however, a complication arises from the fact that a canal, called Skyline canal, takes a considerable portion of the upper tributaries across the divide into the drainage of the South Platte River, taking water away from the State of Wyoming and using it in the drainage basin of the South Platte.[c] No measurements are made in Colorado upon the tributaries

[a] State Engineers' Reports: Second, p. 26; fourth, pp. 35 and 46; fifth, p. 63, and sixth, p. 67. For details concerning the different districts, see the Biennial Reports of State Engineers; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 94 et seq.

[b] See list of miscellaneous measurements, page 69.

[c] See Hayden's Reports; also Nineteenth Annual Report U. S. Geological Survey, Part IV, p. 300; Twentieth Annual Report, Part IV, p. 393; Water-Supply and Irrigation Paper No. 9, p. 42. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97, etc.

of the North Platte, but a station has been maintained for some years upon the Laramie at Woods, in Wyoming, a few miles north of the State line, and the results of these measurements are given in the table for the Laramie at that point (page 60).

The South Platte River itself rises in South Park and flows in a generally northeasterly direction to the northeast corner of the State, which it leaves at a point a short distance below Julesburg. The drainage basin has been so fully described in previous reports and irrigation papers that only a brief description is necessary, the reader being referred to those already printed.[a] In general, the western side of the division is very mountainous, the main stream itself and all the tributaries of that section issuing from high mountains through deep canyons, many of them, however, draining parks at the headwaters, where stock raising and some cultivation of hay is carried on. From the eastern slope of the foothills to the eastern boundary of the State the country is of the plains character, and the streams draining this section are torrential in their nature. The normal flow throughout this entire division is claimed and used for irrigation, but in the high stages of the streams and in the winter season a great deal of water goes to waste which might be stored in suitable reservoirs.

The water districts now included in this division are Nos. 23,[b] 8,[c] 2,[d] 1,[e] and 64,[f] on the South Platte River; No. 9,[f] comprising the territory drained by Bear Creek; No. 7,[g] by Clear Creek; No. 6,[h] by Boulder Creek; No. 5,[h] by St. Vrain Creek; No. 4,[i] by Big Thompson Creek; No. 3,[i] by Cache la Poudre River; Nos. 46, 47, and 48,[j] by tributaries of North Platte River; and No. 65 by tributaries of Kansas River, the latter district being more properly outside of the South Platte River division, although legally a part of it.

STREAM MEASUREMENTS.

The following stations have been maintained for a greater or less time in or near the South Platte division: Cheesman Lake, Platte Canyon, Denver, and Orchard on South Platte River; Morrison, on Bear

[a] See U. S. Geological and Geographical Survey Terr., Hayden, 1875 and 1876. Annual Reports U. S. Geological Survey: Tenth, Part II, p. 69; Thirteenth, Part III, p. 82; Sixteenth, Part II, p. 542; Eighteenth, Part IV, p. 159; Nineteenth, Part IV, p. 311; Twentieth, Part IV, p. 277; Twenty-first, Part IV, p. 200. Also Bulletins No. 131, p. 30, and No. 140, p. 102; Water-Supply and Irrigation Paper No. 37, p. 221; No. 49, p. 278, and Tenth Biennial Report State Engineer of Colorado, p. 246.

[b] Fifth Biennial Report, Part II, Pl. I.

[c] Ibid., Pl. VII; also Seventh Biennial Report.

[d] Ibid., Pl. III; also Seventh.

[e] Ibid., Pl. II; also Seventh.

[f] Ibid., Pl. VIII; also Seventh.

[g] Ibid., Pl. VI; also Seventh.

[h] Ibid., Pl. V; also Seventh.

[i] Ibid., Pl. IV.

[j] Nos. 46, 47, 48, and 65 have not been mapped.

Creek; Forkscreek, on Clear Creek; Marshall, on South Boulder Creek; Boulder, on Boulder Creek; Lyons, on St. Vrain Creek; Arkins, on Big Thompson Creek; Fort Collins, on Cache la Poudre; and Woods in Wyoming, on Laramie River.

The waters of this division are used in all the different ways previously mentioned. In South Park and in the foothills along the east front of the Rocky Mountains water is being extensively stored for domestic use. In the mountains and in places where the fall is great the water is used for the development of power and also for placer mining. After leaving the mountains it is used for irrigation, and already it is being stored extensively for use late in the irrigation season, this being especially true of the territory along the Big Thompson and Cache la Poudre. Cheesman Lake and some of the other reservoirs of the upper portion of the Platte have already been described,[a] as have also a number of those of northern Colorado.[b] There are undoubtedly enough reservoir sites along the South Platte and its tributaries to store all the water that now goes to waste. A number of these on the plains through which the river flows between Greeley and Julesburg are now under consideration.

SOUTH PLATTE RIVER AT CHEESMAN LAKE.

This station has been maintained by the Denver Union Water Company for the purpose of determining the discharge of the South Platte at that point with reference to the construction of a large reservoir for the purpose of providing a sufficient domestic water supply for the city of Denver and of developing power to be transmitted from the lake to various points below. The dam is to be of solid masonry, 217 feet in height, and is already well under way (see Pl. II). The lake when full will be about 7 miles in length, and the capacity will be probably not less than 4,000,000,000 cubic feet. The same company has other large reservoirs at points lower down, but none of equal magnitude with this.[c]

The records are given for only two years. Those for 1899 are approximate, but those for 1900 have been carefully compiled and are very reliable. They are furnished through the courtesy of Mr. C. L. Harrison, chief engineer of the Denver Union Water Company.[d]

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[a] House Doc. No. 141, Fifty-fifth Congress, second session, H. M. Chittenden's Report; Water-Supply and Irrigation Paper No. 37, p. 221; Twenty-First Annual Report U. S. Geol. Survey, Part IV, fig. 192; Tenth Biennial Report of State Engineer, p. 247.

[b] Water-Supply and Irrigation Paper No. 9, and Chittenden's Report above mentioned.

[c] See Chittenden's Report above mentioned, this reservoir being there called the "South Platte site."

[d] For more detailed information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 248; Water-Supply and Irrigation Paper No. 37, pp. 222–223; No. 39, p. 447, and No. 49, p. 280.

Estimated monthly discharge of South Platte River at Cheesman Lake.

[Drainage area, 1,677 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1899.						
August	902	170	354	21,767	0.21	0.24
September[a]	198	105	149	8,926	.09	.10
October[a]	155	34	92	5,657	.05	.06
November[a]	171	55	125	7,438	.07	.08
December	112	44	70	4,304	.04	.04
Last 5 months of the year			[a] 158	48,092	.09	.52
1900.						
January	27	23	26	1,599	.02	.02
February[b]	27	27	27	1,553	.02	.02
March	103	27	80	4,919	.05	.06
April	547	92	254	15,114	.15	.17
May	1,540	562	1,038	63,824	.62	.71
June	1,945	550	1,204	71,643	.72	.80
July	522	40	208	12,789	.12	.14
August	126	58	88	5,410	.05	.06
September	103	63	79	4,701	.05	.06
October	155	39	84	5,165	.05	.06
November	90	37	69	4,106	.04	.04
December	67	18	33	1,964	.02	.02
The year			[a] 266	192,787	.15	2.16

[a] Average. [b] Estimated in part.

List of discharge measurements made on South Platte River at Cheesman Lake.

[Hydrographer, J. A. Runner.]

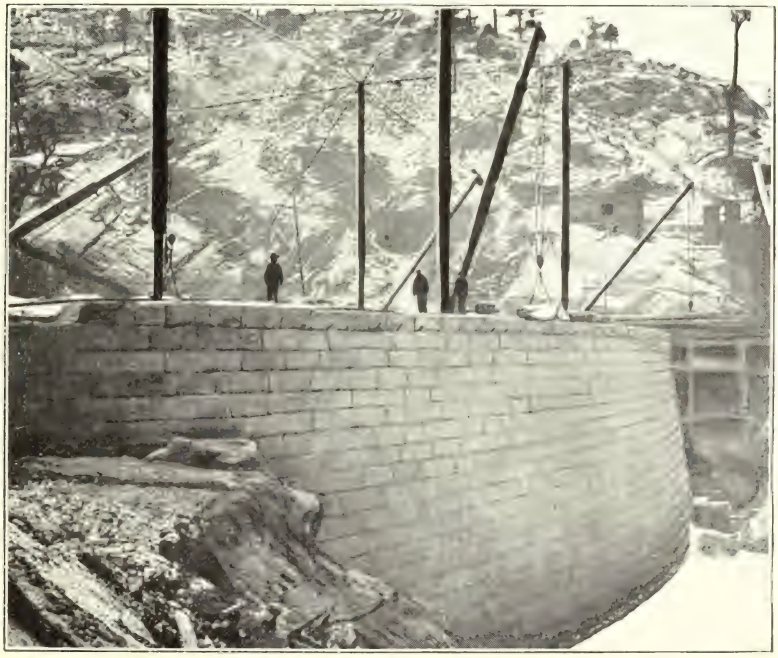
Date.	Gage height.	Discharge.	Remarks.
1899.	*Feet.*	*Sec.-ft.*	
July 31	3.62	806	All gagings are made by floats.
September 8	1.45	184	
October 3	1.23	95	
November 19	1.30	107	
December 5	1.24	97	

List of discharge measurements made on Goose Creek at Cheesman Lake.

[Hydrographer, J. A. Runner.]

Date.	Gage height.	Discharge.	Remarks.
1899.	*Feet.*	*Sec.-ft*	
September 8	0.95	24	All gagings made by floats.
October 8	.84	10	
November 19	.72	8	
December 3	.76	9	

A. DAM AT CHEESMAN LAKE, DOWNSTREAM FACE.



B. DAM AT CHEESMAN LAKE, UPSTREAM FACE.

SOUTH PLATTE RIVER AT PLATTE CANYON.

Records have been kept for a number of years of the discharge of South Platte River at a point a short distance above where it debouches from the mountainous area into the plains. The station was located first at Deansbury, but was later removed to a point about 3 miles downstream, near the pumping station of the Denver Union Water Company. The records for both stations are given in one table, as they are practically the same, no water being used along this section except what is taken out by the Denver Union Water Company at its head gate, which amount would be approximately compensated by the inflow during the same distance. The station is of importance, as it gives the discharge of the river just above the point where it begins to be used on a large scale for irrigation, and is, therefore, of great value in determining the amount available for storage and the percentage of run-off from the territory above. The situation is complicated, however, as has been previously suggested, by the fact that some irrigation is practiced in South Park, for which reason an estimate of the percentage of run-off based upon this record would necessarily be too small. The irrigation ditches of South Park, although small in size, are many in number, and the aggregate of water thus used is considerable. At a point about a mile below the gaging station the first large canal, the Northern Colorado Irrigation Company's canal,[a] is taken out by means of a diverting dam constructed across the river and a tunnel cut through a spur of the canyon wall. The physical conditions at the station are not favorable to extremely accurate measurements, for the channel is filled with bowlders and the current is very rapid. The stream bed is not, however, subject to great change, and for this reason the station has been maintained. Gagings must necessarily be made from a bridge or cable, owning to the depth and velocity of the water. The banks are so high that there is little danger of overflow.[b]

[a] See Twenty-first Annual Report U. S. Geological Survey, Part IV, p. 200; also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101 and 109.

[b] Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 63, and Part II, Pl. XVII; Fifth, Part I, pp. 19 and 24, and Part II, Pl. XI; Sixth, pp. 19 and 26; Eighth, pp. 412 to 419; Ninth, pp 328 and 329; Tenth, pp. 252 to 255. Annual Reports U. S. Geological Survey: Eighteenth, Part IV, p. 159; Nineteenth, Part IV, p. 311; Twentieth, Part IV, p. 280; Twenty-first, Part IV, p. 201. Also, Bulletin U. S. Geological Survey No. 140, p. 103, and Water-Supply and Irrigation Papers, No. 11, p. 52; No 15, p. 87; No. 37, p. 224, No. 39, p. 448, and No. 49, p. 280. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101, 109, 114, and 125.

Discharge of South Platte River at Deansbury and Platte Canyon.

[Drainage area at Deansbury, 2,600 square miles.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	.....	.....	.....	.....	.....	.....	97	81	.....	98	92	5,657	0.04	0.04
February	.....	.....	.....	.....	.....	.....	.....	115	80	.....	53	83	4,610	.03	.03
March	.....	.....	.....	.....	.....	.....	.....	207	101	.....	156	155	9,531	.06	.07
April	295	.....	[a] 172	.....	[b] 142	.....	.....	473	370	454	826	405	24,100	.16	.18
May	470	.....	478	391	[c] 1,117	[d] 630	.....	502	984	760	[g] 424	862	53,002	.33	.38
June	535	.....	460	403	1,243	628	.....	281	1,046	1,346	([f])	743	44,212	.29	.32
July	310	545	324	520	645	847	.....	233	.....	1,161	.....	573	35,233	.22	.25
August	265	550	211	562	373	535	.....	189	.....	587	.....	409	25,148	.16	.18
September	165	410	129	196	219	328	.....	250	.....	233	.....	266	15,828	.10	.11
October	185	300	180	172	.....	292	.....	217	.....	154	.....	214	13,158	.08	.09
November	.....	.....	.....	.....	.....	.....	[e] 241	169	.....	160	.....	190	11,306	.07	.08
December	.....	.....	.....	.....	.....	.....	145	93	.....	160	.....	133	8,177	.05	.06
Mean	318	451	279	374	623	543	193	236	444	557	711	344	249,962	.13	1.79
Acre-feet for period recorded [g]	135,034	109,962	106,922	136,528	187,872	168,012	16,563	170,919	160,395	304,003	212,910	.....	.....	.....	.....

[a] Commencing April 22. [b] April 5 to 12, inclusive. [c] Commencing May 7. [d] Commencing May 29. [e] Commencing November 15.

[f] First two days in June discharge equaled 2,745 second-feet each day.

[g] The run-off for the period covered by the river height observations only; the discharge given above is for average months and an average year, based upon the records kept. The details may be found in the authorities cited for this station.

Maximum and minimum discharge and average run-off of South Platte River at Deansbury and Platte Canyon for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1887	Sept. —	95	June —	785	0.93	0.12
1888	Oct. —	210	July —	670	.70	.15
1889	Sept. 6	92	May 21	788	.77	.11
1890	Oct. 30	112	July 13	875	.98	.14
1891	Apr. 5	121	June 9	1,495	1.37	.24
1892	Oct. 8	270	June 26	962	1.09	.21
1895	Dec. 26	92	Nov. 19	311	.12	.08
1896	Jan. 25	90	Apr. 28	983	1.22	.09
1897	Jan. 28	67	June 1	1,550	1.15	.17
1899	Dec. 5	10	June 20	2,175	2.16	.21
1900	Feb. 14	41	June 1	2,745	1.36	.27

Discharge measurements made on South Platte River at Deansbury and Platte Canyon.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1895.		*Feet.*	*Sec.-ft.*	
Nov. 30	L. R. Hope	4	197	At Deansbury, station No. 1.
Dec. 1	do	3.20	102	Do.
Dec. 7	do	3.60	160	Do.
Dec. 8	do	3.65	166	Do.
Dec. 14	do	3.80	183	Do.
Dec. 20	do	3.35	135	Do.
1896.				
Jan. 12	L. R. Hope	3.05	94	Do.
Jan. 18	do	3.05	94	Do.
Jan. 27	do	2.90	90	Do.
Feb. 4	do	3.18	116	Do.
Feb. 11	do	3.10	101	Do.
Feb. 19	do	2.97	91	Do.
Feb. 23	do	3.42	144	Do.
Mar. 18	do	3.07	97	Do.
Mar. 20	do	3.75	184	Do.
Mar. 30	do	5.15	372	Do.
Apr. 2	do	4.30	259	Do.
Apr. 13	do	4.85	329	Do.
May 3	do	2.70	557	At Deansbury, station No. 2.
May 26	do	2.55	485	Do.
June 9	do	1.90	314	Do.

Discharge measurements made on South Platte River at Deansbury and Platte Canyon—Continued.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1896.		*Feet.*	*Sec.-ft*	
June 14	L. R. Hope	1.44	235	At Deansbury, station No. 2.
July 6	do	.90	138	Do.
July 24	do	1.66	289	Do.
Aug. 14	do	.73	125	Do.
Aug. 25	do	1.30	205	Do.
Sept. 28	do	1.50	239	Do.
Oct. 10	do	1.42	233	Do.
Oct. 20	do	1.23	193	Do.
Oct. 31	do	1.33	212	Do.
Nov. 10	do	1.27	201	Do.
1897.				
Jan. 8	L. R. Hope	2.75	79	At Deansbury, station No. 1.
Jan. 16	do	2.68	85	Do.
Jan. 22	do	2.56	68	Do.
Jan. 31	do	2.33	56	Do.
Feb. 17	do	2.58	72	Do.
Mar. 1	do	2.75	90	Do.
Mar. 11	do	2.82	103	Do.
Mar. 20	do	2.75	92	Do.
Mar. 27	do	3.40	165	Do.
Apr. 8	do	4.17	261	Do.
Apr. 17	do	4.70	343	Do.
Apr. 22	do	5.80	511	Do.
Apr. 8	do	1.67	261	At Deansbury, station No. 2.
Apr. 17	do	2.02	343	Do.
Apr. 22	do	2.62	511	Do.
Apr. 3	do	3.05	644	Do.
Apr. 9	do	3.50	831	Do.
May 25	do	4.15	1,006	Do.
June 10	do	3.85	985	Do.
July 1	do	3.15	678	Do.
1899.				
Apr. 14	J. E. Field	1.80	559	Do.
May 8	A. L. Fellows	1.50	500	Do.
June 10	do	2.90	1,127	Do.
July 28	do	1.80	633	Do.
Oct. 4	do	.10	146	Do.
1900.				
Mar. 5	A. L. Fellows	.40	87	Do.
Apr. 18	do	1.55	467	Do.

A. CASTLEWOOD DAM DURING CONSTRUCTION.

B. CASTLEWOOD LAKE AND DAM.

SOUTH PLATTE RIVER AT DENVER.

Attempts have been made at different times to establish and maintain stations at a number of points in the vicinity of Denver, but the only one that has proved of sufficient value to be kept up is the one located at the Fifteenth street bridge, about 1 mile below the post-office. The location is favorable in some respects, as it is just below the mouth of Cherry Creek, upon which the Castlewood dam (see Pl. III) is situated, the junction of Cherry Creek and the South Platte marking the end of district No. 8 and the beginning of district No. 2. It is, moreover, as favorable a location with reference to channel and banks as can be found anywhere below the point at which the river strikes the sandy plains, where it becomes broad and shallow, with a changeable and shifting bottom. Owing, however, to its being located so near the mouth of Cherry Creek, considerable difficulty is experienced through a deposition of bars of sand and gravel, sometimes along the left bank of the river and again along the right bank, so that occasional changes in gage rods and frequent changes in rating tables are necessary. Measurements at this point are necessarily made as often as possible.

The station is principally valuable as giving information concerning the discharge at the head of irrigation district No. 2, so that the division of water among consumers may be regulated by the water commissioner with greater facility. Measurements are made from the bridge, except at low water, when they may be made by wading.[a]

[a] For more detailed information concerning this station see Biennial Reports of State Engineers of Colorado: Fifth, Part I, p. 26, Part II, pl. 12; Sixth, p. 19; Eighth, p. 420; Ninth, p. 330; Tenth, p. 256. Annual Reports U. S. Geological Survey: Eighteenth, Part IV, p. 162; Nineteenth, Part IV, p. 313; Twentieth, Part IV, p. 279; Twenty-first, Part IV, p. 201. Bulletin U. S. Geological Survey No. 140, p. 104. Water-Supply and Irrigation Papers, No. 11, p. 53; No. 15, p. 88; No. 27, pp. 84, 86, 89; No. 37, p. 225; No. 39, p. 448; and No. 49, p. 281. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 101, 109, 114.

Discharge of South Platte River at Denver.

[Altitude, 5,183 feet; drainage area, 3,840 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.[a]	Mean run-off.	
									Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	182	95	164	55	204	140	8,608	0.04	0.04
February	.....	198	83	153	196	193	164	9,108	.04	.04
March	.....	225	179	121	409	184	223	13,711	.06	.07
April	.....	301	470	377	466	1,634	649	38,619	.17	.19
May	.....	291	735	1,444	432	4,187	1,418	87,190	.37	.43
June	.....	200	1,026	1,552	821	2,817	1,283	76,344	.33	.37
July	854	164	392	672	637	370	515	31,666	.13	.15
August	742	115	687	328	527	148	424	26,071	.11	.13
September	426	145	270	187	286	123	239	14,222	.06	.07
October	698	111	267	146	109	104	239	14,695	.06	.07
November	456	101	406	131	202	179	246	14,638	.06	.07
December	204	103	217	98	146	178	157	9,653	.04	.04
Mean	563	178	402	448	357	860	475	344,525	.12	1.67
Acre-feet for period recorded[a]	206,070	128,837	291,996	325,006	258,850	632,690	.....	.....	.....	.....

[a] The run-off given is for the period covered by the observations of each year. That given in the vertical columns is for average months and years from all the data obtained. Details for these years may be seen in authorities cited for this station.

Maximum and minimum discharge and total run-off of South Platte River at Denver for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec. ft.		*Sec.-ft.*		
1895	Dec. 23	108	Aug. 2	1,945	1.19	0.14
1896	Oct. 11	27	July 25	758	.62	.05
1897	Feb. 13	16	Aug. 5	2,458	1.426	.105
1898	Dec. 23	50	May 28	2,308	1.58	.12
1899	Jan. 22	42	Aug. 5	1,422	1.257	.093
1900	Oct. 7	51	Apr. 29	5,510	2.92	.22

Discharge measurements made on South Platte River at Denver.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-feet.*
May 7	P. J. Preston		168
July 23	F. Cogswell	5.40	1,490
Aug. 7	P. J. Preston	4.60	876
Aug. 22	do	3.90	447
Nov. 9	do	4.30	430
Nov. 29	do	3.90	303
1896.			
Jan. 6	P. J. Preston	3.60	183
Apr. 8	do	4.50	235
May 29	do	4.90	304
July 1	do	4.33	107
July 25	do	6.10	1,316
Aug. 5	do	4.35	125
Aug. 26	R. A. Sumner	4.80	83
Sept. 11	F. Cogswell	5.10	163
Oct. 30	P. J. Preston	4.70	93
Nov. 9	do	4.75	100
1897.			
Jan. 15	P. J. Preston	4.70	98
Apr. 15	F. Cogswell	5.35	385
May 1	do	5.70	595
May 25	do	5.85	778
June 4	do	6.45	1,311
June 15	do	6.75	1,406
July 13	do	5.60	687
Aug. 5	do	7.45	1,849
Aug. 20	do	5.55	473
Sept. 6	do	4.95	116
Oct. 11	do	5.70	413

Discharge measurements made on South Platte River at Denver—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Apr. 21	A. L. Fellows	5.90	564
July 6	do	6.10	443
Sept. 2	do	5.50	195
Oct. 8	do	5.00	90
Oct. 29	F. Cogswell	5.32	234
1899.			
Apr. 12	A. L. Fellows	6.00	422
May 11	do	6.03	355
June 12	do	6.20	764
July 27	do	5.32	213
Aug. 4	do	6.93	1,200
Sept. 6	do	5.95	288
Oct. 5	do	5.10	100
1900.			
Mar. 6	A. L. Fellows	5.50	244
Apr. 12	do	5.90	377
Apr. 16	do	7.24	1,439
Apr. 20	do	7.10	1,395
Apr. 23	do	8.32	3,516
June 11	do	8.50	3,270
July 25	do	5.45	257
Aug. 7	do	5.56	285
Aug. 29	do	4.90	90
Oct. 20	R. W. Hawley	5.50	226
Oct. 22	do	5.30	161

SOUTH PLATTE RIVER AT ORCHARD.

This station was established November 20, 1895, for the purpose of furnishing data relative to the flow of South Platte River in the winter months and during flood stages, but later was maintained throughout the entire year for the purpose of determining the total discharge. It is situated some distance below all the mountain drainage of the stream and below the territory in which there is the greatest return from seepage. For three years the rod was located in a bend of the river about one-fourth of a mile southwest of the railroad station at Orchard, but later a new rod was placed at the wagon bridge south of the town, and since that time readings have been taken at the latter point, for the reason that it was necessary to make the gagings from the wagon bridge at times of high water. The channel throughout this entire region is broad and shallow, the bottom being sandy and shifting, rendering frequent changes in the rating tables necessary.

The investigations at this point have demonstrated that great amounts of water go to waste, and private capital has been enlisted for the construction of the reservoirs of the South Platte Land, Reservoir and Irrigation Company in the vicinity of Orchard. The reservoirs of this company consist of natural basins located in the plains on each side of the river, all water being diverted from the river to the reservoir sites by means of large canals.[a]

[a] For more detailed information concerning this station see Biennial Reports of State Engineers of Colorado: Eighth, p. 426; Ninth, p. 333; Tenth, p. 261. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 166; Nineteenth, Part IV, p. 315; Twentieth, Part IV, p. 293; Twenty-first, Part IV, p. 203; Bulletin No. 140, p. 112; Water-Supply and Irrigation Papers No. 11, p. 53; No. 15, p. 89; No. 27, pp. 84, 86, and 89; No. 37, p. 226; No. 39, p. 448, and No. 49, p. 282. Also Report on Agriculture by Irrigation, Eleventh Census, pp. 122 and 132.

Discharge of South Platte River at Orchard.

[Altitude, 4,393 feet; drainage area, 12,260 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.	
									Sec.-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	775	631	[a]1,068	[a]2,880	[a]1,634	[a]1,397	[a]85,898	[a]0.11	[a]0.13
February	.....	[b]610	557	811	[a]3,321	[a]1,268	[a]1,313	[a]72,920	[a].11	[a].11
March	.....	581	231	574	[a]2,377	[c]683	[c]889	[a]54,662	[a].07	[a].08
April	.....	.....	529	380	[a]1,325	4,180	[a]1,603	[a]95,386	[a].13	[a].14
May	.....	.....	898	1,946	465	8,617	2,981	183,294	.23	.26
June	.....	.....	2,637	776	1,198	4,638	2,312	137,574	.19	.21
July	.....	.....	347	173	1,593	171	571	35,110	.05	.06
August	.....	.....	803	40	761	114	429	26,378	.03	.03
September	.....	.....	92	69	45	142	87	5,177	.01	.01
October	.....	.....	303	215	429	431	344	21,151	.03	.03
November	[d]870	.....	[a]1,109	811	799	611	840	49,983	.07	.08
December	759	789	[a]1,232	[a]2,651	[a]1,544	614	[a]1,264	77,720	.10	.12
Mean	814	688	[a]789	[a]792	[a]1,394	[a]1,925	[a]1,269	[a]845,253	[a].10	[a]1.26
Acre-feet for period recorded [e]	62,199	148,829	564,500	551,150	1,009,225	1,453,570	.....	.....	.....	.....

[a] The calculations are from the gage heights reported by the observer, but the discharge given for the winter months is probably much too high, owing to ice gorges raising the water on the gage. The winter discharge marked (c) was also probably very much less than the figures would indicate.

[b] February 16 to 29, inclusive.

[d] Commencing November 22.

[e] The run-off per acre-foot given is for that period of each year covered by the observations, the discharge given is for average months and years from all data available. The details for these years may be seen in the authorities cited for this station.

Maximum and minimum discharge and average run-off of South Platte River at Orchard for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 22	818	Dec. 1	1,031	0.095	0.07
1896	Dec. 27	213	Jan. 9	960	.226	.06
1897	July 8	39	June 14	5,160	.851	.064
1898	Apr. 28	10	May 29	3,214	.90	.07
1899	June 12	10	Feb. 27	3,966	1.56	.11
1900	Aug. 16	113	May 2	11,159	2.16	.16

Discharge measurements made on South Platte River at Orchard.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
Nov. 20	P. J. Preston	4.00	829
Dec. 27	do	3.83	667
1896.			
Feb. 19	H. A. Sumner	3.98	669
Oct. 22	P. J. Preston	3.20	240
Dec. 12	do	4.55	550
1897.			
Jan. 18	P. J. Preston	4.14	377
May 28	L. R. Hope	5.00	1,921
June 20	R. S. Sumner	4.68	1,926
June 27	do	3.20	504
July 25	do	3.60	524
Sept. 13	do	2.50	86
Nov. 9	do	4.40	1,299
1898.			
Apr. 24	A. L. Fellows	2.20	71
May 30	do	4.60	3,214
July 9	do	2.25	32
Aug. 9	do	2.25	36
Nov. 6	F. Cogswell	2.80	302
Nov. 17	do	3.15	491
1899.			
Apr. 14	A. L. Fellows	3.20	1,258
May 27	do	2.30	158
Sept. 12	do	2.05	57
Nov. 3	M. D. Williams	2.80	614

Discharge measurements made on South Platte River, at Orchard—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 7	A. L. Fellows	2.85	668
Apr. 21	do	5.00	4,674
July 23	do	1.35	156
Oct. 27	R. W. Hawley	2.70	324

SOUTH PLATTE RIVER AT JULESBURG.

Although no station has been regularly maintained at this point, a number of measurements, which are given in the table below, have been made here at different times. The location is important from the fact that it is near the line between Colorado and Nebraska, so that discharge measurements at this point indicate the flow from the one State into the other. The channel is broad and shallow, the bottom being sandy and shifting. A gage rod was fastened to the wagon bridge 1 mile southeast of Julesburg in the spring of 1900, but no records were kept. Measurements may be made either from the wagon bridge or at low water by wading. The majority of the gagings at this point were made by employees of the State engineer's office in connection with the annual seepage measurements of the South Platte River.[a]

Discharge measurements made on South Platte River, at Julesburg.

[Altitude 3,560 feet.]

Date.	Gage height.	Discharge.
	Feet.	*Sec.-ft.*
November 5, 1891		43
November 4, 1894		2
November 14, 1895		586
September 4, 1899		2
November 12, 1899		487
March 8, 1900	2.10	2,291
November 2, 1900		76

BEAR CREEK AT MORRISON.

Bear Creek is the first important tributary received by South Platte River after it leaves the mountains. Information concerning the discharge of this stream is important, as it supplies a large proportion of the water furnished to Denver by the Denver Union Water Company,

[a] See also Tenth Biennial Report of the State of Colorado, p. 265. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 131.

storage reservoirs having been provided for this purpose in Marston and Harriman lakes. Nearly the entire flow of this stream is used for the water supply of Denver and for irrigation, there being a scarcity of water along the stream except for the earliest priorities during a large portion of almost every irrigation season. Like all mountain streams, it is subject to sudden and violent rises from sharp and severe storms at its headwaters.[a]

The station was located for some years about the center of the town of Morrison, but in the spring of 1899 it was moved to a point just above Morrison, at the headgate of the Denver Union Water Company's pipe line. The conditions have generally been rather unfavorable to correctness of measurements, as the channel is somewhat changeable, being made up of loose bowlders, and at the dam where the water is diverted into the pipe line gravel bars have formed, changing the natural conditions. Measurements have been made by wading, excepting at the highest stages of the water, when they have been made from the wagon bridge just above the town of Morrison.[b]

[a] For full description see Hayden's Report of 1875, p. 432.

[b] For further details concerning this station see Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 61, and Part II, Pl. XX; Fifth, Part I, p. 30, and Part II, Pl. XIV; Sixth, pp. 20 and 31; Eighth, p. 454; Ninth, p. 336; Tenth, pp. 223 and 266. Publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 167; Nineteenth, Part IV, p. 317; Twentieth, Part IV, p. 284; Twenty-first, Part IV, p. 204; Bulletin No. 140, p. 106; Water-Supply and Irrigation Papers, No. 11, p. 54; No. 15, p. 90; No. 27, pp. 81 and 86; No. 37, p. 227; No. 39, p. 448, and No. 49, p. 284. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 114.

Discharge of Bear Creek at Morrison.

[Altitude, 5,565 feet; drainage area, 179 square miles.]

Month.	1888.	1889.	1890.	1891.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean runoff.		
												Equivalent in acre-feet.	Depth in inches.	Second-feet per square mile.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	31	.....	.....	[b]50	.....	[c]49	.....	.....	[l]84	[n]306	104	6,188	0.68	0.61
May	95	[f]701	63	195	[g]69	51	[f]152	[f]117	103	487	144	8,731	.98	.85
June	100	[h]85	31	289	[i]183	32	175	143	93	379	151	8,985	.99	.89
July	65	49	34	90	136	[j]33	115	150	86	145	87	5,349	.59	.51
August	55	[k]58	24	32	122	[l]53	199	68	104	51	77	4,673	.52	.45
September	30	.....	20	25	69	50	67	45	31	[m]27	40	2,380	.27	.24
October	.....	.....	21	.....	[o]61	35	55	29	[o]21	29	36	2,152	.24	.21
November	.....	.....	17	.....	.....	.....	34	23	.....	16	22	1,309	.14	.13
December	.....	.....	.....	.....	.....	.....	[m]20	.....	.....	.....	20	1,190	.14	.12
Mean [p]	63	73	30	113	107	44	102	82	75	176	76	40,957	4.55	.45
Acre-feet [p]	3,749	4,344	1,785	6,724	6,367	2,618	6,069	4,879	4,463	10,472	.....	.....	.....	.....

[a] The discharge given is for average months, and the total for an average period of nine months, as shown by the observations. Details may be found in the authorities cited for this station.

[b] Commencing April 5.
[c] Commencing April 6.
[d] Commencing April 16.
[e] Commencing April 14.
[f] Commencing May 3.
[g] For May 19 to 31, inclusive.
[h] June 9 to 19, inclusive, is missing.
[i] June 3 to 12, inclusive, is missing.
[j] July 25 to 31, inclusive, is missing.
[k] Ending August 10.
[l] August 1 to 5, inclusive, is missing.
[m] Approximated.
[n] Ending October 5.
[o] Ending October 21.
[p] For period covered.

Maximum and minimum discharge and average run-off of Bear Creek at Morrison for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. —	30	June —	100	0.41	0.37
1889	May 3	18	May 20	195	.48	.43
1890	Nov. 15	15	July 23	75	.20	.18
1891	Sept. 22	12	May 27	622	.73	.66
1895	May 20	41	June 13	274	.70	.63
1896	July 14	9	Apr. 2	86	.29	.26
1897	Nov. 24	5	Aug. 3	385	.67	.60
1898	Nov. 23	20	July 13	2,083	.54	.48
1899	Oct. 21	17	Aug. 4	325	.49	.44
1900	Nov. 23	10	Apr. 29	691	1.15	1.03

Discharge measurements made on Bear Creek at Morrison.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 18	P. J. Preston	0.90	47
June 12	do	2.05	331
July 24	do	1.65	171
Oct. 7	do	1.05	64
1896.			
June 17	P. J. Preston	.75	32
Aug. 4	do	2.90	55
Sept. 19	R. S. Sumner	3.05	80
Oct. 31	P. J. Preston	2.55	16
1897.			
May 20	R. L. Hope	3.60	179
June 13	R. S. Sumner	3.70	209
June 26	do	3.50	162
July 24	do	3.45	131
Sept. 11	F. Cogswell	3.05	55
Oct. 12	do	3.00	52
1899.			
Apr. 15	J. E. Field	3.80	64
May 9	A. L. Fellows	4.25	99
June 6	do	4.25	107
Aug. 5	do	4.98	192
Nov. 14	do	1.35	13

Discharge measurements made on Bear Creek at Morrison—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 9	A. L. Fellows	1.40	17
Apr. 14	do	2.85	47
Apr. 25	do	5.80	367
Aug. 7	do	3.20	63
Sept. 6	do		24

CLEAR CREEK AT FORKSCREEK.

Clear Creek is one of the largest tributaries of South Platte River, issuing from the mountains, and emptying into the main stream about 6 miles below Denver. Like the other streams of this region, it flows for a long distance through a mountainous territory (see Pl. IV, A) and then discharges into the plains, where its water is used for irrigation. The establishment of a station at Forkscreek, which is about 12 miles up the canyon, was for the purpose of determining not only the amount of its water that may be available for irrigation and storage, but the amount that may be used for the development of power. The water of Clear Creek is used to such an extent for placer mining and for the development of power for use in stamp mills that the name "Clear Creek" has long since become a misnomer, the stream being anything but clear. After the stream empties into the plains the greater part of the water is used for irrigation, there being comparatively little surplus even during the flood stages.[a]

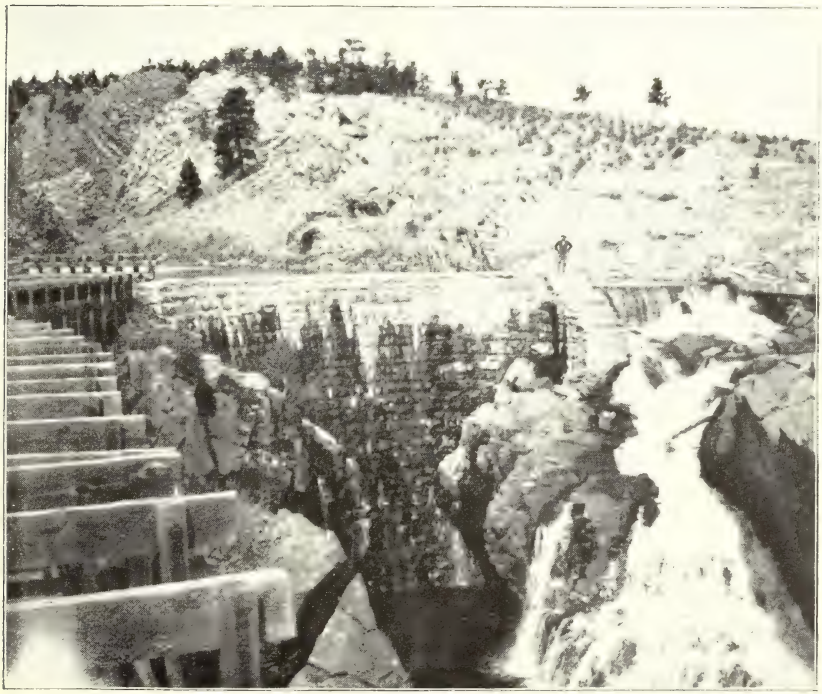
Measurements were also made in the years 1887 and 1888 at a point below the mouth of the canyon, and estimates were made for the year 1898 by the water commissioner of the Clear Creek water district. The discharges of these years are too unreliable to be incorporated into the table, but they are given by themselves.

Results obtained at this station are not entirely satisfactory, as the channel consists of bowlders and the fall is great, the banks being high and rocky. There is, moreover, no suitable method of crossing the river, the bridges being unsatisfactory, so that most of the measurements have been taken at low-water stages.[b]

[a] For full description of this drainage basin see Hayden's Report, of 1875, p. 432; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 114.

[b] For further details concerning this station see Biennial Reports of State Engineer of Colorado: Fourth, Part I, p. 63, and Part II, Pl. XVIII; Fifth, Part I, p. 18; Sixth, p. 20; Ninth, p. 340; Tenth, pp. 222 and 270. Publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 205; Water-Supply and Irrigation Papers, No. 37, p. 228; No. 39, p. 448 and No. 49, p. 286. Report on Agriculture by Irrigation, Eleventh Census, p. 114.

A. CLEAR CREEK CANYON ABOVE FORKS CREEK.



B. HOME SUPPLY DAM ON BIG THOMPSON CREEK.

Discharge of Clear Creek at Golden.

[In cubic feet per second.]

Year.	Average for month.						
	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1897	621	793	516	304	181	130	.....
1898	285	650	420	120	75	70	57

NOTE.—This table was furnished by W. N. Palmer, water commissioner for the Clear Creek district for 1897 and 1898. The winter discharge is given as about 50 second-feet.

Estimated monthly discharge of Clear Creek at Forkscreek.

[Altitude, 6,892 feet; drainage area, 345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April	403	51	180	10,711	0.52	0.58
May 1 to 19	1,202	192	581	35,724	1.68	1.94
June 7 to 30	1,373	775	1,081	64,324	3.13	3.49
July	1,202	614	791	48,637	2.30	2.66
August	692	299	440	27,005	1.28	1.48
September	349	155	214	12,734	0.62	.69
October	155	133	141	8,670	0.41	.47
November	155	32	77	4,582	0.22	.24
Total	.....	.....	.....	212,387	.....	11.55
1900.						
March 10 to 31	75	44	60	2,619	0.17	.20
April	403	58	178	10,592	0.52	.58
May	1,259	367	789	48,514	2.29	2.64
June	1,259	714	968	57,601	2.80	3.12
July	719	235	378	23,242	1.10	1.27
August	235	84	137	8,424	0.40	.46
September	75	44	58	3,451	0.17	.19
October	75	51	58	3,566	0.17	.20
November	58	51	52	3,094	0.15	.17
Total	.....	.....	.....	161,103	.....	8.83

Discharge measurements made on Clear Creek at Forkscreek.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Mar. 24	J. E. Field	1.50	52
Apr. 20	do	2.10	155
May 10	A. L. Fellows	2.75	365
June 7	do	3.70	779
Aug. 12	do	3.08	449
Nov. 15	do	1.70	67
1900.			
Mar. 10	do	1.60	55
Apr. 13	do	1.70	73
Apr. 24	do	2.60	290
Aug. 27	do	1.78	130

ST. VRAIN CREEK NEAR LYONS.

St. Vrain Creek and its tributaries receive their supply of water from the eastern slope of that portion of the Front Range lying between Longs Peak and James Peak, a distance of about 30 miles. The general trend of the drainage is northeastward, the St. Vrain flowing at last into South Platte River about 6 miles below the town of Platteville. The principal tributaries of the St. Vrain are the North and South Forks and the Boulder, the South Boulder being an important branch of the latter. The areas drained by the upper portions of these streams are all alike mountainous, the streams flowing through deep and rugged canyons, where the water can be used only for the development of power and for placer mining; but upon leaving the foothills each one of them emerges into a broad and nearly level valley where farming by irrigation is extensively practiced.[a]

Three stations have been maintained upon the St. Vrain and its tributaries, one located at a point about one-half of a mile east of Lyons, upon the St. Vrain, one at a point at the mouth of the canyon of the Boulder, a mile above the town of Boulder, and one at a point in the mouth of the South Boulder Canyon about 3 miles west of Marshall.

Records have been kept of the gage heights at the Lyons station since April, 1888, except during the years 1893 and 1894, when very little hydrographic work was done in Colorado. A number of changes in the location and position of the gage rod have been necessary, but these have not affected the value of the tables, the station being always practically the same. As maintained at the present time the station is opposite the Tower Hotel. Most of the measurements are made by

[a] For full description of this basin see Hayden's Report of 1875, p. 436. Also Report on Agriculture by Irrigation, Eleventh Census, p. 103.

wading, but at high water they are made from a bridge located about one-quarter of a mile below the station. The channel is favorable to good results, lying in small bowlders and cobblestones, and the banks are so high that overflow is improbable. The table of discharge includes the amount carried by the Supply ditch, which is taken out above the station but of which records were also kept.[a]

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[a] For more detailed data concerning this station see Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 63, and Part II, Pl. XIX; Fifth, Part I, pp. 18 and 28, Part II, Pl. XIII; Sixth, pp. 20 and 28; Eighth, p. 436; Ninth, p. 348; Tenth, pp. 213 and 280. See also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 172; Nineteenth, Part IV, p. 320; Twentieth, Part IV, p. 285; Twenty first, Part IV, p. 208; Bulletin No. 140, p. 109; Water-Supply and Irrigation Papers, No. 11, p. 55; No. 15, p. 93; No. 27, pp. 83, 86, and 89; No. 37, p. 232; No. 39, p. 448; and No. 49, p. 288. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

Discharge of St. Vrain Creek at Lyons.

[Drainage area, 209 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.[c]	1895.	1896.	1897.	1898.	1899.	1900	Mean.	Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	72	.....	.....	165	.....	.....	96	.....	.....	222	361	183	10,889	0.88	0.98
May	156	[a] 465	[b] 376	629	([e])	.....	259	[d] 571	243	300	657	406	24,964	1.94	2.24
June	320	371	436	1,046	856	[f] 790	363	766	483	829	709	634	37,726	3.03	3.38
July	208	197	292	516	587	469	225	506	261	734	290	390	23,980	1.87	2.16
August	133	102	179	151	155	243	167	303	113	330	107	180	11,068	.86	.99
September	56	44	66	96	89	98	139	127	68	95	72	86	5,117	.41	.46
October	50	39	45	.....	65	197	65	50	22	44	49	63	3,874	.30	.35
November	.....	.....	30	.....	.....	.....	37	.....	20	24	31	28	1,666	.13	.14
Mean[f]	142	203	203	434	350	359	169	387	173	322	285	246	119,284	1.18	10.70
Acre-feet[f]	60,415	66,495	80,600	159,380	106,182	100,392	81,740	140,544	73,402	155,916	138,304	.....	.....	.....	.....

[a] May 20 to 31 inclusive.

[b] May 15 to 31 inclusive.

[c] Stations were maintained upon both forks of the St. Vrain in 1892. The monthly averages given are the sums for the two forks. The average for May 29 to 31 on South Fork was 373 second-feet and from May 26 to 31 on North Fork was 231 second-feet.

[d] Commencing May 2.

[e] Commencing June 13.

[f] For period covered by observations.

Maximum and minimum discharge and average run-off of St. Vrain Creek at Lyons for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	June —	[a] 320	Oct. —	[a] 50	0.75	0.68
1889	May 28	548	Oct. 13	26	1.08	.97
1890	June 2	675	Nov. 15	18	1.08	.97
1891	May 27	1,397	Apr. 5	31	2.32	2.08
1892	June 24	1,480	Oct. 28	53	1.86	1.67
1895	June 16	1,127	Sept. 14	80	1.92	1.72
1896	May 30	666	Oct. 26	21	.90	.81
1897	June 11	1,052	Nov. 16	31	2.06	1.85
1898	June 17	637	Nov. 26	21	.91	.82
1899	June 20	1,275	Nov. 11	16	1.72	1.54
1900	Apr. 29	918	Mar. 17	10	1.52	1.36

[a] May 29 to 31 inclusive.

Discharge measurements made on St. Vrain Creek at Lyons.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-feet.*
May 11	P. J. Preston	1.65	260
July 20	do	3.40	336
Oct. 2	do	2.10	65
1896.			
June 6	P. J. Preston	3.57	389
July 29	do	2.70	189
Sept. 22	R. S. Sumner	2.50	110
Oct. 14	P. J. Preston	2.22	53
1897.			
May 25	L. R. Hope	4.15	659
June 17	R. S. Sumner	4.40	713
June 28	do	3.70	551
July 20	do	3.10	379
Sept. 15	F. Cogswell	2.10	115
Nov. 10	do	1.75	54
1898.			
May 27	A. L. Fellows	2.80	256
July 12	do	3.10	308
Aug. 5	do	2.20	73
Oct. 12	do	1.85	20

Discharge measurements made on St. Vrain Creek at Lyons—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-feet.*
Apr. 18	J. E. Field	3.00	217
May 5	A. L. Fellows	2.75	137
June 14	do	4.15	825
Aug. 9	do	3.20	263
Oct. 7	do	2.10	37
1900.			
Mar. 13	A. L. Fellows	2.06	35
Apr. 27	do	3.68	513
July 27	do	2.70	193

BOULDER CREEK NEAR BOULDER.

The general nature of Boulder Creek, which is one of the tributaries of the St. Vrain, has already been noted in the description of the main stream.[a]

The gaging station is located 1½ miles above the town of Boulder, in the mouth of the canyon. There are two small irrigation ditches above the station, but the amount of water diverted does not exceed 5 or 6 second-feet, and may therefore be disregarded. The channel of the stream consists of large bowlders throughout its entire course, and it is therefore difficult to make accurate measurements. Gagings are usually made by wading, but may be made from a wagon bridge just above the gage rod at high water. The normal flow is entirely used for irrigation, but during the flood season a large proportion goes to waste. Fillings have, however, been made upon a number of reservoir sites in this drainage basin, by means of which most of the surplus water might be stored.[b]

[a] For a description of this drainage basin, see Hayden's Report of 1875, p. 135. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

[b] Biennial Reports of State Engineers of Colorado: Fourth, Part I, p. 64, and Part II, Pl. XXI; Fifth, Part I, pp. 18 and 32, and Part II, Pl. XV; Sixth, pp. 21 and 33; Eighth, p. 442; Ninth, p. 345; Tenth, pp. 224 and 277. Also publications U. S. Geological Survey: Annual Reports, Eighteenth, Part IV, p. 171; Nineteenth, Part IV, p. 319; Twentieth, Part IV, p. 286; Twenty-first, Part IV, pp. 207–208; Bulletin No. 140, p. 108; Water-Supply and Irrigation Papers, No. 11, p. 55; No. 15, p. 92; No. 27, pp. 82, 86, and 89; No. 37, p. 248; No. 49, p. 287. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

Discharge of Boulder Creek at Boulder.

[Altitude, 5,347 feet; drainage area, 179 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.	
														Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	81	.....	.....	.....	.....	.....	80	.....	.....	117	.....	93	5,534	0.52	0.58
May	164	[a] 676	[b] 287	[c] 327	[d] 336	[e] 316	240	323	233	353	625	353	21,705	1.97	2.27
June	261	565	341	427	447	502	264	458	447	663	640	456	27,134	2.55	2.84
July	210	277	258	240	372	355	150	339	213	577	255	295	18,139	1.65	1.90
August	157	97	[f] 173	116	148	205	88	213	62	265	94	147	9,039	0.82	0.94
September	80	34	56	[g] 61	47	86	73	83	30	87	54	63	3,749	0.35	0.39
October	60	36	[h] 33	.....	43	44	33	47	8	39	33	38	2,337	0.21	0.24
November	.....	.....	[i] 26	.....	.....	.....	.....	38	40	24	.....	32	1,904	0.12	0.13
Mean [j]	145	281	168	234	232	251	133	214	148	266	284	185	89,541	1.03	9.29
Acre-feet [j]	61,632	98,589	59,607	58,464	74,520	85,158	56,496	90,736	62,916	128,832	103,592	.....	.....	.....	.....

[a] Commencing May 8.
[b] Commencing May 13.
[c] Commencing May 18.
[d] Commencing May 23.
[e] Commencing May 14.
[f] August 12 to 14 missing.
[g] Ending September 20.
[h] October 16 to 19 missing.
[i] November 3 to 9, inclusive.
[j] For period covered by records.

Maximum and minimum discharge and average run-off of Boulder Creek at Boulder for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-feet		*Sec.-feet.*		
1888	April —	25	June —	350	0.90	0.81
1889	Sept. 20	16	May 31	785	1.75	1.57
1890	Nov. 7	23	Aug. 4	1,200	1.03	0.93
1891	Sept. 16	54	June 8	540	1.46	1.31
1892	Oct. 19	27	June 23	646	1.45	1.30
1895	Oct. 29	5	June 3	750	1.56	1.40
1896	Apr. 3	7	May 30	809	0.82	0.74
1897	Nov. 16	23	June 10	745	1.34	1.20
1898	Nov. 30	3	June 18	560	1.36	1.22
1899	Nov. 29	13	July 2	847	1.66	1.49
1900	Oct. 31	7	June 1	801	1.77	1.59

[a] The run-off given is the amount for that part of each year covered by the records and for an average month of thirty days, at the rate given as the mean for the period covered.

Discharge measurements made on Boulder Creek near Boulder.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
July 17	P. J. Preston	1.90	317
Oct. 13	do	.50	36
1896.			
July 2	P. J. Preston	1.30	139
July 30	do	1.10	110
Sept. 23	R. S. Sumner	.80	69
Oct. 16	P. J. Preston	.50	35
1897.			
May 21	L. R. Hope	2.15	442
July 26	R. S. Sumner	1.75	298
Aug. 12	F. Cogswell	1.55	224
Oct. 13	do	.55	48
1898.			
Apr. 17	A. L. Fellows	.78	69
May 28	do	1.85	367
July 16	J. E. Field	1.50	266
Aug. 3	A. L. Fellows	.86	62
Oct. 11	do	.28	12

Discharge measurements made on Boulder Creek near Boulder—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 21	J. E. Field	1.00	84
May 6	A. L. Fellows	1.20	134
June 15	do	2.50	642
Aug. 10	do	1.70	276
Otc. 20	do	.50	36
1900.			
Apr. 28	A. L. Fellows	2.10	483
July 27	do	1.40	220
Aug. 28	do	.62	49

SOUTH BOULDER CREEK AT MARSHALL.

South Boulder Creek is a tributary of the Boulder, and its drainage basin lies north of and adjoins that of Clear Creek.[a] The station has been maintained for each irrigation season since April, 1888, except during 1893 and 1894. The rod consists of an inclined timber on the north bank of the stream, near the house of C. E. Barber. Two ditches take their water supply from the stream at points above the station, these being the South Boulder and Coal Creek ditch and the Community ditch, and their discharges are added to the discharge as found at the station, so as to give the total run-off of the basin. The channel of the stream is rocky and full of bowlders, but does not change materially. Gagings are usually made by wading, but at high water they may be made from the foot bridge just above the rod.[b]

[a] For description see Hayden's Report of 1875, p. 436. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 103.

[b] For more detailed data concerning this station see Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 64, and Part II, Pl. XXIII; Fifth, Part I, p. 36. and Part II, Pl. XVII; Sixth, pp. 21 and 36; Eighth, p. 448; Ninth, p. 341; Tenth, pp. 225 and 273. Also publications of U. S. Geological Survey, Eighteenth Annual Report, Part IV, p. 169; Nineteenth, Part IV, p. 318; Twentieth, Part IV, p. 287; Twenty-first, Part IV, p. 206; Bulletin No. 140, p. 107; Water-Supply and Irrigation Papers, No. 11, p. 54; No. 15, p. 91; No. 27, pp. 82, 86, and 89; No. 37, p. 229, and No. 49, p. 286. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell. p. 103.

Discharge of South Boulder Creek at Marshall.

[Altitude, 5,498 feet; drainage area, 125 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	100	.....	.....	58	.....	.....	72	.....	.....	123	.....	88	5,236	0.70	0.78
May	135	[b] 475	[c] 313	366	[d] 237	[e] 288	232	[f] 332	208	332	.....	292	17,954	2.34	2.70
June	.....	335	349	356	374	592	208	458	325	539	356	371	22,076	2.97	3.31
July	130	152	143	140	232	243	75	235	138	319	93	173	10,637	1.38	1.59
August	98	39	64	45	62	120	43	129	42	121	29	72	4,427	.58	.67
September	40	21	39	20	21	39	37	43	22	35	9	30	1,785	.24	.27
October	.....	20	[g] 31	[h] 19	18	38	23	39	20	.....	.....	26	1,599	.21	.24
November	.....	.....	.....	.....	.....	.....	.....	35	18	.....	.....	26	1,547	.21	.23
Mean[i]	115	174	157	143	157	220	99	182	110	245	121	135	65,261	1.08	9.79
Acre-feet[i]	41,724	54,855	52,878	52,824	53,492	74,188	41,947	76,893	46,652	88,938	29,280	.....	.....	.....	.....

[a] The run-off is for average months, and the total for an average period of eight months as shown by the observations. Details may be found in the authorities cited for this station.

[b] Commencing May 26.

[c] Commencing May 9.

[d] Commencing May 13.

[e] Commencing May 15.

[f] Commencing May 2.

[g] Ending October 25.

[h] Ending October 3.

[i] For period covered by the observations.

Maximum and minimum discharge and average run-off of South Boulder Creek at Marshall for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. —	30	June —	225	1.02	0.92
1889	Oct. 12	15	May 31	560	1.55	1.39
1890	Sept. 20	19	May 28	542	1.41	1.26
1891	Sept. 19	15	May 17	565	1.27	1.14
1892	Oct. 13	15	June 24	561	1.41	1.26
1895	Oct. 1	14	June 3	1,090	1.96	1.76
1896	Oct. 6	18	May 30	603	.88	.79
1897	Nov. 7	18	June 11	595	1.63	1.46
1898	Nov. 18	9	June 17	444	.98	.88
1899	Sept. 21	9	June 21	663	2.19	1.96
1900	Sept. 16	5	June 2	582	1.08	.94

Discharge measurements made on South Boulder Creek at Marshall.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 14	P. J. Preston	2.00	164
July 18	do	2.00	195
Oct. 10	do	1.05	42
1896.			
July 3	P. J. Preston	1.50	88
Aug. 8	do	0.96	27
Sept. 24	R. S. Sumner	1.00	31
Oct. 17	R. J. Preston	0.90	24
1897.			
May 22	L. R. Hope	2.45	348
June 19	R. S. Sumner	2.60	363
June 25	do	2.50	370
July 27	do	1.65	122
Aug. 13	F. Cogswell	1.55	116
Oct. 14	do	0.82	14
1898.			
Apr. 23	A. L. Fellows	1.35	72
May 29	do	2.29	274
July 11	do	1.70	130
Aug. 6	do	1.15	47
Oct. 10	do	0.55	2

Discharge measurements made on South Boulder Creek at Marshall.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 22	J. E. Field	1.70	115
May 6	A. L. Fellows	1.55	96
June 15	do	2.80	451
Aug. 10	do	1.60	109
Oct. 10	do	0.70	7
1900.			
July 28	A. L. Fellows	1.40	35
Aug. 28	do	1.10	10

BIG THOMPSON CREEK AT ARKINS.

This stream drains considerable territory north of Longs Peak, and is one of the largest tributaries of the South Platte, into which it flows about 4 miles above the town of Evans. The Little Thompson is an important tributary of the Big Thompson, and the country drained by these two streams forms irrigation district No. 4 (see Pl. IV, *B*). The two streams come together a short distance above where their combined waters enter the South Platte.[a]

Records were begun upon this stream in April, 1888, and have been maintained for a portion of each year since that time, except in the years 1893 and 1894. The location of the station has been changed several times, having been below both the Handy and the Home Supply ditches a portion of the time and above the Home Supply and below the Handy at other times. At present it is located at the upper point, so that only the waters carried by the Handy ditch need to be added to give the total run-off of the basin. The amounts given in the tables are for the combined flow. Irrigation is practiced on a small scale about 20 miles above the station also, but to such a limited extent that it may be disregarded.[b]

[a] For description see Hayden's Report for 1875, p. 437; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 116–119.

[b] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Second, p. 6; Fourth, Part I, p. 64, and Part II, Pl. XXII; Fifth, Part I, pp. 18 and 34, and Part II, Pl. IX; Sixth, pp. 21 and 34; Eighth, p. 430; Ninth, pp. 310 and 333; Tenth, pp. 215. 216 and 284. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 174; Nineteenth, Part IV, p. 321; Twentieth, Part IV, p. 288; Twenty-first, Part IV, p. 209; Bulletin No. 140, p. 110; Water-Supply and Irrigation Papers, No. 11, p. 56, No. 15, p. 94; No. 27, pp. 83, 86, and 89; No. 37, p. 233; No. 39, p. 448; and No. 49, p. 290. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 116–119.

Discharge of Big Thompson Creek at Arkins.

[Altitude, 5,255 feet; drainage area, 305 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
														Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	62	.....	.....	.....	.....	.....	.....	.....	.....	156	432	217	12,912	0.71	0.79
May	132	[b] 359	[c] 436	.....	[d] 312	[e] 482	295	590	231	353	1,432	462	28,407	1.51	1.74
June	458	382	530	[f] 817	704	943	363	679	499	1,037	1,497	719	42,783	2.36	2.64
July	275	200	454	383	498	683	259	379	317	766	379	418	25,702	1.37	1.58
August	190	89	393	159	150	441	172	196	112	316	149	215	13,220	.70	.81
September	75	49	151	95	49	194	161	71	57	102	87	99	5,891	.32	.36
October	46	46	67	.....	.....	121	96	54	23	64	.....	65	3,997	.21	.24
November	.....	.....	[g] 83	.....	.....	.....	.....	54	18	.....	.....	52	3,094	.17	.19
Mean[h]	177	188	302	364	343	477	224	289	180	399	663	281	136,006	.92	8.35
Acre-feet[h]	75,114	61,545	115,008	85,918	100,520	156,090	81,696	122,622	76,398	169,274	240,645	.....	.....	.....	.....

[a] The run-off is for average months and the total for an average period of eight months as shown by the observation. Details may be found in the authorities cited.
[b] Commencing May 20.
[c] Commencing May 8.
[d] Commencing May 15.
[e] Commencing May 20.
[f] Commencing June 4.
[g] To November 15, inclusive.
[h] For period covered by observations.

Maximum and minimum discharge and average run-off of Big Thompson Creek at Arkins for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Apr. 3	30	June 16	862	0.64	0.58
1889	Oct. 2	28	May 31	546	.69	.62
1890	Oct. 7	51	July 21	1,603	1.10	.99
1891	Sept. 17	69	June 25	1,182	1.33	1.19
1892	Sept. 29	39	June 21	1,195	1.25	1.12
1895	Oct. 2	58	June 2	1,102	1.74	1.56
1896	Oct. 26	76	May 30	1,200	.81	.73
1897	Nov. 18	54	June 11	1,040	1.04	.94
1898	Oct. 24	14	June 24	722	.65	.59
1899	Apr. 9	25	June 21	1,852	1.46	1.31
1900	Apr. 2	30	May 30	2,223	2.42	2.17

[a] The run-off given is the amount for that part of each year covered by the records and for an average month of thirty days at the rate given as the mean for the period covered.

Discharge measurements made on Big Thompson Creek at Arkins.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
May 9	P. J. Preston	1.25	260
July 19	do	1.90	499
Oct. 1	do	.45	42
1896.			
June 1	P. J. Preston	1.70	403
July 28	do	1.50	286
Oct. 15	do	.80	74
1897.			
May 26	L. R. Hope	2.45	804
June 18	R. S. Sumner	1.60	400
June 27	do	1.50	409
July 21	do	1.20	214
Sept. 16	F. Cogswell	.60	61
Nov. 11	do	.65	79
1898.			
May 26	A. L. Fellows	1.25	263
July 13	do	1.60	444
Aug. 4	do	.70	87
Oct. 14	do	.40	30

Discharge measurements made on Big Thompson Creek at Arkins—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 17	J. E. Field	0.90	143
May 4	A. L. Fellows	.97	173
June 13	do	2.55	941
Aug. 8	do	1.73	406
Oct. 6	do	.50	34
1900.			
Apr. 26	A. L. Fellows	1.91	512
July 26	do	1.35	322

CACHE LA POUDRE RIVER AT FORT COLLINS.

This stream is the largest and the northernmost of the tributaries discharging from the east front of the Rocky Mountains into the South Platte. During the irrigation season its discharge is augmented by the supply diverted from the headwaters of the Laramie River, which heads immediately west of the headwaters of the Cache la Poudre, the diversion being made through a canal known as the Skyline canal, already mentioned (p. 21). Measurements of the discharge of the Cache la Poudre Basin therefore include some of the Laramie waters. As is the case with other streams of this region, the normal flow is almost entirely consumed for irrigation, and even the greater part of the flood waters is stored for late use. The earliest and most thorough irrigation of the State is carried on along this stream.[a] The station was established in 1884 at a point about 15 miles above Fort Collins, and has been maintained ever since that time under the direction of Prof. L. G. Carpenter, of the Colorado State Agricultural College.[b]

The following tables are compiled from records published from time to time by Professor Carpenter, the first table showing the normal discharge as calculated by him for the irrigating season, and the second giving a summary of discharge for the entire time. The results are to a certain extent misleading, as additions have been made to the normal discharge of the stream from year to year through the Skyline canal, taking its water from the headwaters of the Laramie

[a] Water-Supply and Irrigation Paper No. 9 and Department of Agriculture Bulletin No. 92.

[b] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Second, p. 6 and Appendix B; Third, pp. 5 and 62; Fourth, Part I, p. 61, and Part II, Pl. IX; Fifth, Part I, pp. 17 and 22; Sixth, pp. 19 and 22; Seventh, p. 172; Ninth, p. 356; Tenth, p. 288. Also, publications U. S. Geological Survey: Thirteenth Annual Report, Part III, p. 94; Twentieth, Part IV, p. 290; Bulletin No. 131, p. 30; No. 140, p. 112; Water-Supply and Irrigation Papers, No. 9, p. 16; No. 37, p. 235, and No. 49, p. 291. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

River, and this increase is not considered in the tables. In computing the average monthly discharge only those months are included for which the record is complete, or at least estimated:

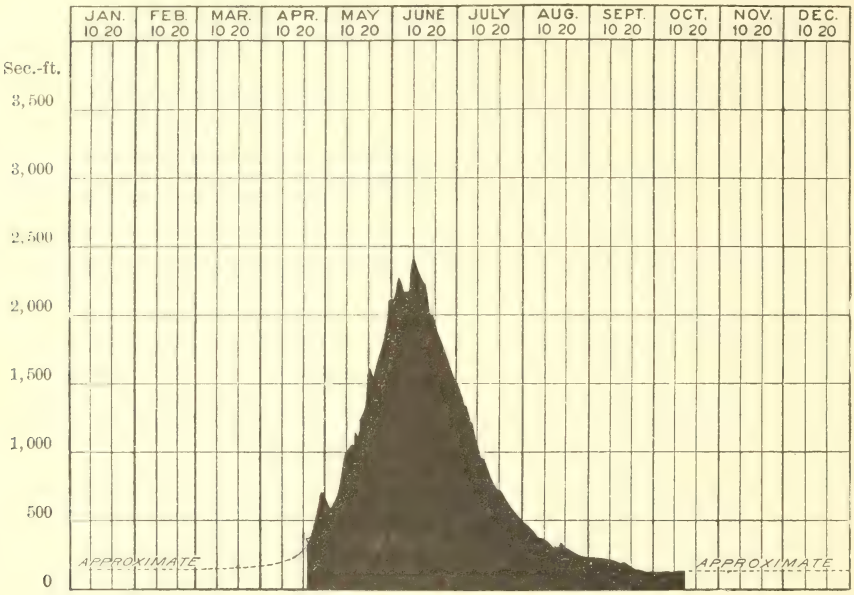


Fig. 1.—Normal discharge of Cache la Poudre River.

Normal discharge of Cache la Poudre River at Fort Collins for the years 1884 to 1900, inclusive.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1	.....	589	2,052	1,426	490	245	147
2	.....	597	2,120	1,399	485	238	137
3	.....	611	2,250	1,328	479	228	133
4	.....	634	2,207	1,290	469	[a] 225	137
5	.....	686	2,108	1,213	438	[a] 222	133
6	.....	729	2,149	1,152	[a] 426	[a] 219	131
7	.....	784	2,136	1,154	414	[a] 216	132
8	.....	842	2,165	1,118	383	[a] 213	133
9	.....	916	2,268	1,069	395	[a] 210	130
10	.....	974	2,385	1,029	398	[a] 207	139
11	.....	999	2,319	954	374	204	129
12	.....	1,024	2,271	965	358	189	129
13	.....	1,012	2,227	951	339	182	132
14	.....	1,046	2,188	871	338	170	130
15	.....	1,109	2,171	856	324	166	127
16	.....	1,232	2,123	814	338	168	.....
17	.....	1,240	2,038	794	325	161	.....
18	.....	1,259	1,959	774	387	154	.....
19	.....	1,311	2,005	737	333	151	.....
20	.....	1,446	1,913	694	317	146	.....
21	.....	1,625	1,966	704	306	144	.....
22	.....	1,547	1,881	650	299	140	.....
23	.....	1,534	1,810	611	291	139	.....
24	367	1,625	1,783	[a] 597	284	144	.....
25	406	1,720	1,755	[a] 583	280	148	.....
26	446	1,804	1,741	[a] 569	262	147	.....
27	541	1,890	1,633	[a] 555	251	148	.....
28	607	1,985	1,619	[a] 542	252	145	.....
29	706	1,980	1,561	[a] 529	251	143	.....
30	651	2,046	1,472	[a] 515	240	141	.....
31	.....	2,028	.....	502	247	.....	.....

[a] Interpolated.

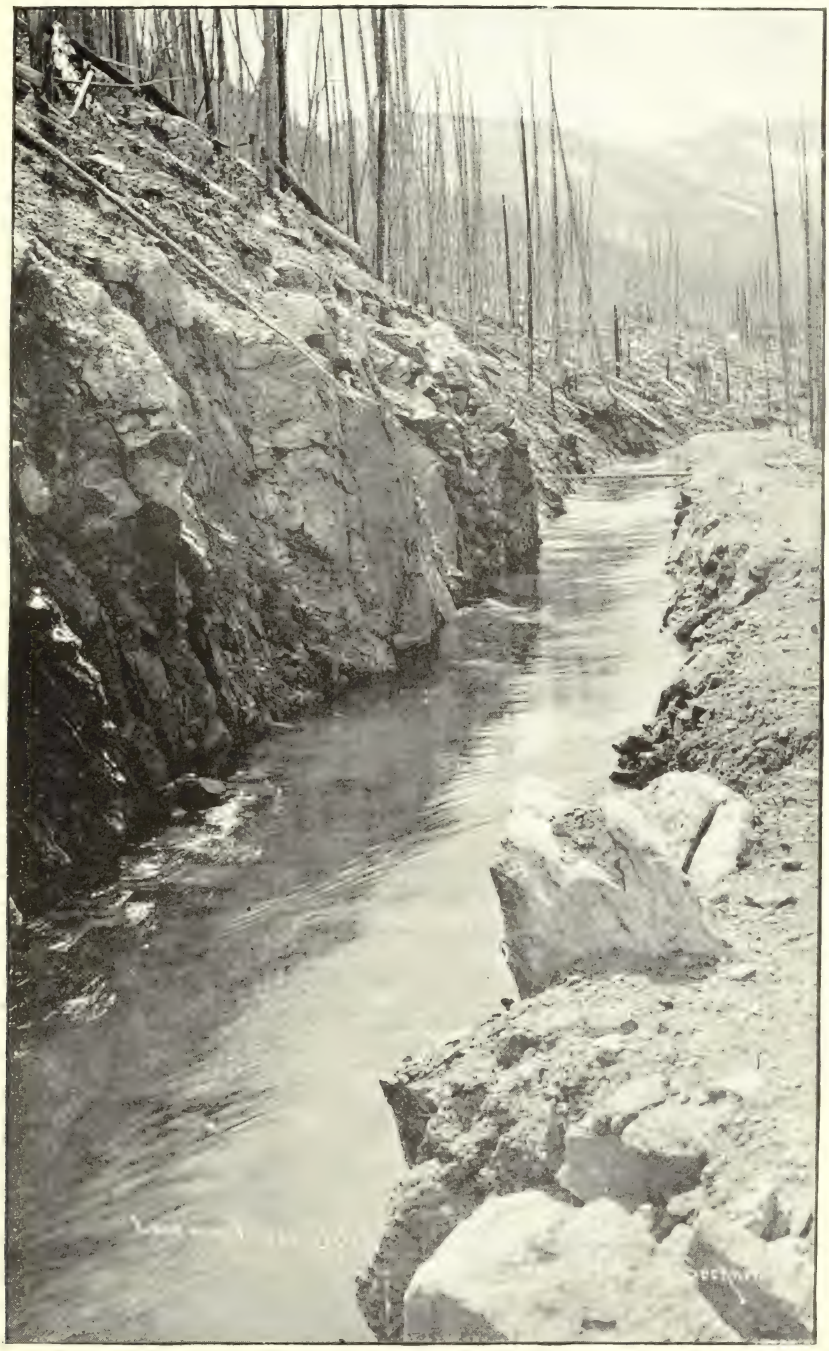
Discharge of Cache la Poudre River at Fort Collins for the years 1884 to 1900, inclusive.

[Altitude, 4,994 feet; drainage area, 1,060 square miles.]

Month.	1884.	1885.	1886.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off. Equivalent in acre-feet.	Mean run-off. Second-feet per square mile.	Mean run-off. Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	.....	.....	.....	.....	151	82	92	64	.....	.....	*a* 90	.....	.....	.....	.....	.....	96	5,903	0.09	0.10
February	.....	.....	.....	.....	.....	106	79	79	179	.....	.....	*a* 90	.....	.....	.....	.....	.....	95	5,464	.09	.09
March	67	.....	.....	.....	.....	46	85	59	80	.....	.....	*a* 90	.....	.....	.....	.....	.....	72	4,427	.07	.08
April	219	*b* 447	*d* 405	*a* 200	181	113	200	144	*a* 100	.....	.....	*a* 390	.....	.....	.....	.....	*e* 1,376	193	11,484	.18	.20
May	2,537	1,419	1,309	*ac* 1,822	483	649	1,044	1,221	*a* 250	*b* 762	*b* 1,436	*ac* 1,216	.....	*a* 2,052	*a* 649	*a* 1,207	2,808	1,302	80,057	1.23	.42
June	4,812	2,910	1,875	*ac* 1,401	1,113	1,338	1,280	1,900	1,512	*b* 1,815	2,063	*a* 2,382	*e* 774	1,731	1,309	2,632	2,942	2,128	126,625	2.01	2.24
July	2,144	1,857	717	735	420	514	649	541	741	617	833	1,117	458	749	478	1,441	721	867	53,310	.82	.94
August	792	656	338	307	213	187	287	228	*a* 200	*b* 235	339	495	272	*a* 352	*a* 147	557	265	352	21,644	.33	.38
September	305	273	185	175	109	67	103	138	.....	.....	164	*a* 219	*a* 273	*a* 177	*a* 78	212	149	175	10,413	.16	.18
October	.....	1,203	129	*a* 120	*a* 90	69	80	118	.....	.....	105	*a* 160	.....	.....	*a* 59	110	*e* 132	204	12,543	.19	.22
November	.....	.....	.....	.....	.....	88	61	83	.....	.....	*b* 95	*a* 110	.....	.....	.....	.....	.....	86	5,117	.08	.09
December	.....	.....	.....	.....	.....	64	70	79	.....	.....	.....	*a* 90	.....	.....	.....	.....	.....	76	4,673	.07	.08
Mean *i*	1,761	1,196	747	720	400	482	567	671	753	811	804	914	520	793	451	1,027	1,266	471	341,660	.44	6.02
Acre-feet *i*	660,177	448,308	279,909	269,892	149,877	180,684	212,625	251,559	*e* 168,709	*f* 194,040	301,403	342,657	195,048	297,108	168,966	374,808	457,002	.....	.....	.....	.....

a Estimated or interpolated in part.
b Between 20 and 31 days.
c Between 10 and 20 days.
d Less than 10 days.
e From May 17 to September 6, inclusive.
f From May 10 to September 6, inclusive.
g From May 1 to October 31, inclusive.
h From April 18 to October 16, inclusive.

i The mean and the run-off in acre-feet given is the amount for 27 weeks from April 26 to November 1, excepting where otherwise stated in the notes, and the corresponding amount for an average month of thirty days at the rate given as the mean for the period covered, while the discharge is for average months and the total for an average year as derived from the observations for all complete months, parts of months not being included in this average, although estimated entire months are. Details may be found in the authorities cited.



SKYLINE CANAL, NEAR GREELEY.

Maximum and minimum discharge and average run-off of Cache la Poudre River at Fort Collins for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1884	Mar. 22	30	June 28	5,611	1.85	1.66
1885	Oct. 5	220	June 3	3,815	1.26	1.13
1886	Oct. 13	110	May 29	2,666	.83	.75
1887	Sept. 18	110	June 7	2,500	.75	.68
1888	Sept. 19	90	June 15	1,550	.43	.38
1889	Dec. 17	33	June 1	1,960	.50	.45
1890	Nov. 16	39	June 2	1,804	.59	.53
1891	Mar. 31	32	June 10	3,600	.70	.63
1892	Mar. 17	40	June 21	2,535	.79	.71
1893	Aug. 31	151	June 12	2,949	.84	.76
1894	Nov. 17	42	June 6	3,672	.84	.76
1895	Sept. 18	174	June 10	3,429	.95	.86
1896	Aug. 18	192	May 30	2,771	.55	.49
1897	Oct. 1	121	May 24	3,155	.83	.75
1898	Oct. 1	35	June 17	1,699	.48	.43
1899	Oct. 7	92	June 21	3,968	1.08	.97
1900	Sept. 20	113	May 29	4,560	1.33	1.19

LARAMIE RIVER AT WOODS, WYO.

This stream, already briefly described on pages 21 and 55, rises in North Park in Northern Colorado, and flows northerly into Wyoming. There is little irrigation from Laramie River in Colorado, except that a portion of the supply of the Cache la Poudre district is supplied from this source, as already mentioned on pages 21 and 55 (see Pl. V).

The data for this station is published through the courtesy of Mr. A. J. Parshall, deputy State engineer of Wyoming.[a]

[a] For more detailed information, see publications U. S. Geological Survey, Eighteenth Annual Report, Part IV, p. 142; Nineteenth, Part IV, p. 300; Twentieth, Part IV, p. 274; Twenty-first, Part IV, p. 192; Bulletin, No. 131, p. 28; No. 140, p. 95; Water-Supply and Irrigation Papers, No. 11, p. 50; No. 15, p. 81; No. 27, pp. 78, 86, and 88; No. 37, p. 214; No. 39, p. 447, and No. 49, p. 273. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 251.

Discharge of Laramie River at Woods, Wyo.

[Drainage area, 435 miles.]

Month.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off.[a] Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b] 200	128	129	571	125	231	13,745	0.53	0.59
May	619	1,964	636	1,284	1,940	1,288	79,196	2.96	3.41
June	465	1,564	969	3,221	1,776	1,599	95,147	3.68	4.09
July	127	266	89	1,253	111	369	22,689	.85	.98
August	94	93	44	191	50	94	5,780	.22	.25
September	116	65	40	56	44	64	3,808	.15	.17
October	[b] 120	[b] 60	[b] 45	65	.....	73	4,489	.17	.20
November	.....	[b] 65	[b] 40	[b] 70	.....	58	3,451	.13	.14
Mean	249	526	249	839	674	472	228,305	1.09	9.83
Acre-feet for period recorded	105,716	254,736	120,536	406,016	243,271	.....	.....	.....	.....

[a] The run-off given is for that part of each year covered by the observations (and estimates) given and for a thirty-day month at the rate given as the mean for the whole period covered, while the discharge given is for average months, and the total for an average eight months from April to November, inclusive, as calculated from the bservations (and estimates). Details may be found in the authorities cited.

[b] Approximate for the month.

Maximum and minimum discharge and average run-off of Laramie River at Woods, Wyo., for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1896	Aug.	49	May	2,166	0.63	0.57
1897	Apr.	48	May	3,435	1.35	1.21
1898	Sept.	40	May	1,572	.63	.57
1899	Oct. 1	45	June 25	4,502	2.15	1.93
1900	Sept. 1	40	May 31	3,995	1.73	1.55

Discharge measurements made on Laramie River at Woods, Wyo.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Sept. 27	W. M. Gilcrest		27
Sept. 28	do		57
Nov. 3	do		80
1895.			
May 24	W. M. Gilcrest	2.80	1,129
Oct. 23	do	0.80	49
1896.			
Apr. 20	W. M. Gilcrest	0.85	75
May 25	do	2.40	797
June 16	do	1.75	350
June 27	Elwood Mead	1.25	198
Aug. 19	W. M. Gilcrest	0.85	81
Aug. 30	do	0.80	75
Oct. 2	C. T. Johnston	1.00	121
1897.			
Apr. 10	C. T. Johnston	0.70	69
May 12	do	2.30	1,110
May 25	do	4.10	3,538
June 1	do	3.60	2,509
June 2	do	3.75	2,651
June 14	do	2.65	1,432
June 26	do	2.00	707
June 27	do	2.00	706
1898.			
Apr. 30	C. T. Johnston	1.40	362
May 22	do	2.00	758
June 4	do	[a] 2.30	1,017
June 4	do	[b] 2.40	1,123
June 5	do	2.10	823

Discharge measurements made on Laramie River at Woods, Wyo.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
May 26	A. J. Parshall	3.30	2,598
June 8	do	3.10	2,319
June 21	do	4.40	4,145
July 6	do	2.80	2,194
1900.			
May 4	A. J. Parshall	1.60	460

[a] At 6 a. m. [b] At 7.30 p. m.

MISCELLANEOUS MEASUREMENTS.

The following table of miscellaneous measurements upon South Platte River and its tributaries is compiled from the Colorado State Engineers' Biennial Reports, and from all other available sources. They are at various points in the division and are valuable for the information furnished as to the discharge at given times.

Miscellaneous gagings in the South Platte River Basin.

[Compiled from the seepage measurements made by the State engineer's office at Denver, Colo.]

Stream.	Locality.	1889.		1890.		1891.		1892.		1893.		1894.	
		Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.
			Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
South Platte River	Platte Canyon	Oct. 18 to Oct. 25	131	Oct. 14 to Oct. 24	209	Oct. 23 to Nov. 5	204	Mar. 7 to Mar. 15	153	Oct. 30 to Nov. 10	133	Oct. 16 to Nov. 4	186
Plum Creek	Mouth		3		2		3		15		6		6
South Platte River	Littleton		13		193		85		222		39		67
Bear Creek	Mouth		3		4		7		13		7		9
South Platte River	Denver		66		241		90		284		77		219
Clear Creek	Mouth		1		1		1		68		1		8
South Platte River	Brighton		8		127		74		272		36		109
Do	Platteville		10		98		90		332		7		97
St. Vrain Creek	Mouth		18		21		29		71		36		62
Big Thompson Creek	do		7		24		13		35		11		28
South Platte River	Evans		46		27		88		450		86		214
Cache la Poudre River	Mouth		15		33		61		146		64		74
South Platte River	Below Poudre		120		213		.....		.....		.....		312
Do	Orchard		.....		156		107		.....		105		.....
Do	Fort Morgan		.....		25		.....		834		.....		.....
Do	Snyder		.....		13		187		.....		51		142
Do	Merino		8		8		97		.....		5		32
Do	Sterling		6		12		67		.....		13		21
Do	Crook		0		4		40		.....		.....		36
Do	Julesburg		0		.....		43		.....		.....		2
Cache la Poudre	Canyon	Oct. 14	69	Oct. 16	81	Oct. —	98	Mar. —	65	Nov. —	52	Mar. —	99
Do	Below Larimer and Weld canal.	Oct. 15	33	do	77	do	54	do	.....	do	69	do	49
Do	Below Cache la Poudre canal.	Oct. 16	2	Oct. 17	2	do	56	do	.....	do	.....	do	.....
Do	Below Ogilvie ditch.	Oct. 17	3	Oct. 18	.....	do	.....	do	141	do	93	do	57
Do	Near mouth	do	10	do	33	do	61	do	176	do	61	do	77

Miscellaneous gagings in the South Platte River Basin—Continued.

Stream.	Locality.	1895.		1896.		1897.		1898.		1899.		1900.	
		Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.	Date.	Amount.
			Sec.-ft.		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*		*Sec.-ft.*
South Platte River	Platte Canyon	Nov. 7	237	Nov. 6	153	Nov. 19	235	Oct. 27	228	Oct. 23	154	Oct. 19	98
Plum Creek	Mouth	Nov. 8	11	Nov. 7	6	Nov. 20	43	Oct. 28	15	Oct. 24	4	Oct. 20	3
South Platte River	Littleton	...do	294	...do	43	...do	259	Oct. 29	158	...do	60	...do	89
Bear Creek	Mouth	...do	24	...do	8	...do	48	...do	14	Oct. 26	13	...do	11
South Platte River	Denver	Nov. 9	430	Nov. 9	100	...do	878	...do	234	Oct. 27	89	Oct. 22	161
Clear Creek	Mouth	Nov. 11	54	...do	66	Nov. 22	52	Oct. 31	1	...do	0	...do	1
South Platte River	Brighton	Nov. 12	373	Nov. 10	132	Nov. 23	360	Nov. 1	62	Oct. 28	81	Oct. 23	82
Do	Platteville	Nov. 13	480	Nov. 11	173	Nov. 24	445	Nov. 2	65	Oct. 30	141	Oct. 24	44
St. Vrain Creek	Mouth	...do	82	Nov. 12	52	Nov. 25	77	Nov. 3	39	...do	95	...do	53
Big Thompson Creek	...do	...do	41	...do	35			...do	16	Oct. 31	39	...do	17
South Platte River	Evans	Nov. 14	648	...do	294			...do	225	Nov. 1	335	...do	193
Cache la Poudre River	Mouth	Oct. 21	123	Nov. 13	85			Nov. 4	74	...do	151	Oct. 25	85
South Platte River	Below Poudre	...do	827	...do	360			...do	302	...do	575	...do	299
Do	Orchard	Oct. 24	941	Oct. 22	940			Nov. 17	491	Nov. 3	614	Oct. 27	324
Do	Fort Morgan	Oct. 26	745	Oct. 24	41			Nov. 18	555	Nov. 4	703	...do	14
Do	Snyder	...do	686	...do	21			Nov. 19	533	Nov. 5	741	Oct. 29	26
Do	Merino	Oct. 28	692	Oct. 26	13					Nov. 7	553	Oct. 30	18
Do	Sterling	Oct. 29	672	...do	30					Nov. 8	581	Oct. 31	30
Do	Crook	Oct. 30	626	Oct. 28	31					Nov. 9	582	Nov. 1	51
Do	Julesburg	Oct. 31	586							Nov. 12	487	Nov. 2	76
Cache la Poudre	Canyon	Oct. 9	66	Nov. —								Sept. 4	118
Do	Below Larimer and Weld canal.	Oct. 10	1									Sept. 30	15
Do	Below Cache la Poudre canal.	Oct. 14	34	Nov. 13	10							Sept. 5	10
Do	Below Ogilvie ditch.	Oct. 15	71	Nov. 14	49								
Do	Near mouth	...do	117	...do	78							Sept. 7	45

[a] Measurements stopped by storms.

SEEPAGE MEASUREMENTS.

The subjoined tables, taken from the records of the state engineer's office of Colorado, illustrates the extraordinary return from seepage along the South Platte and its tributaries. Measurements have been made annually for a number of years, whenever circumstances would permit, by the state engineer's office and the agricultural college at Fort Collins, Colo., working in cooperation, from the year 1889, inclusive. As may be seen from the tables, the return from seepage increases irregularly from year to year, being naturally considerably less during a very dry year than during a wet year. The year 1896, for example, was very dry, and the returns were much less than they would have been normally. The year 1898 was again dry, and the return was again small.[a]

[a] For more detailed information upon this subject see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 559 to 573; Sixth, pp. 51 to 65; Seventh, 176 to 195; Eighth, 381 to 404; Ninth, 305 to 317; Tenth, 208 to 236. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 133.

Increase in volume of the South Platte River from the canyon to points measured, due to the return of waste or seepage waters.

Places where measurements were taken.	Oct., 1889.	Oct., 1890.	Oct., 1891.	Mar., 1892.	Oct., 1893.	Oct., 1894.	Oct. and Nov., 1895.	Oct. and Nov., 1896.	Nov. 19 to 25, 1897.	Oct. and Nov., 1898.	1899.	1900.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
River below Head City ditch			27.57	25.32	18.41	49.23	20.12	10.18		1.21	72.93	33.96
River at Littleton	49.91	11.73	80.18	69.95	41.91	74.82	75.44	24.94		27.65	133.89	74.13
River at Denver	50.91	55.61	96.38	129.56	83.18	193.74	193.24	58.89	62.32	89.28	150.29	90.35
River at Fulton ditch		94.41	138.85	141.51	127.03	228.06	174.05	74.61	138.24	112.78	196.90	86.96
River at Brighton	77.02	98.91	175.19	116.17	152.91	278.04	207.13	126.81	160.79	138.94	274.38	160.62
River at Evans's No. 2 ditch					208.74	314.72	276.76	171.24	237.29	227.92	324.33	
River at Elwood & Wheeler ditch	119.10	172.35	218.69	136.33								
River at Platteville	133.38		226.93	180.54	218.82	343.05	341.57	219.05	291.54	251.29	363.05	216.70
River above St. Vrain Creek		155.80	233.32									
River at Union ditch					252.81	398.70	362.28	228.78		328.41	410.74	257.76
River at Evans	197.00	176.91	299.21	192.86	279.93	450.51	385.85	256.64		362.26	474.59	330.80
River at Cache la Poudre		215.20	326.13	216.17	318.20	474.86	413.05	276.88		466.31		353.43
River at Hoover ditch	277.10	351.66	392.66	285.25		549.75	557.58	309.71		482.47	564.07	
River at Hardin ditch					387.23	498.70	522.31	325.33		497.38		409.08
River at Putnam ditch		333.60	418.80	330.61	365.78	549.12	565.26	344.63		522.39	624.97	412.94
River at Orchard							671.86	344.99		553.41	628.22	439.54
River at Fort Morgan canal	305.92	360.58	434.05	360.09	414.33							
River at Shaffers Ford						617.43	717.78	375.38		568.32	715.57	469.07
River above Bijou Creek						676.88	800.92	392.85		594.40		
River at Platte and Beaver canal	307.03	367.09	472.14	431.74	464.04	631.45						
River at Fort Morgan							799.37	425.24		617.01	722.71	
River at Snyder		384.18	470.60		479.67	707.64	814.19	478.03		654.14	795.34	596.50
River below Big Beaver Creek						714.90	879.57	499.41				
River at Merino	385.58	405.71	550.32		514.39	766.31	959.45	544.24			829.21	682.54
River at Sterling	418.33	435.16	583.69		548.15		1,006.25	576.84			962.94	744.07
River 2 miles above Iliff	422.77	449.21	611.76		572.99		1,023.24	598.20			1,009.13	749.26
River 2 miles above Crook			598.69			810.11						
River at Crook							975.19	629.28			1,078.51	772.90
River at Pole Creek							989.93					
River at State line			602.00			775.94	942.30				1,119.74	800.19

KANSAS RIVER BASIN.

A considerable portion of eastern Colorado is drained by the headwaters of Kansas River, the principal tributaries being branches of Republican and of Smoky Hill rivers. These streams, unlike the other streams of Colorado, do not originate in the mountains; they derive their water supply directly from the run-off and underground flow of the plains. The measurements of the General Land Office show that there are about 9,459 square miles in Colorado belonging to this drainage basin. This territory, although not belonging physically either to the South Platte division or to the Arkansas division, is divided in accordance with the Colorado laws between the two, the lands drained by the North and Middle forks of the Republican and their tributaries constituting district No. 65 and being apportioned to irrigation division No. I, the South Platte division; while the lands drained by the South Fork of the Republican and the Smoky Hill rivers and their tributaries constitute district No. 49 and are allotted to irrigation division No. II, the Arkansas division. The water supply of all these streams is small, but a number of ditches have been constructed and irrigation is carried on so far as it is possible. Only a few gagings have been made upon these streams in Colorado, and these are given below in the list of miscellaneous measurements. Stations have been maintained in Nebraska, however, and some of the records of those nearest to the Colorado line are given, as found in the records of the U. S. Geological Survey.[a]

FRENCHMAN RIVER AT WAUNETA AND PALISADE, NEBR.

The station at Wauneta was located in 1895. It is the highest station upon the Frenchman, being about 25 miles east of the line between Colorado and Nebraska. The channel has not proved favorable to accurate results and the station was therefore discontinued in 1896.

The station at Palisade was located October 14, 1894, at a point about three-fourths of a mile above the railroad station at Palisade, or about 16 miles below the gaging station at Wauneta. The results were unsatisfactory here, also, and the station was discontinued in 1896.

The results have considerable importance in connection with any investigation of the Colorado water supply, as the greatest source of supply for the streams of this section is the underground flow of eastern Colorado.

[a] For more detailed information concerning this drainage basin see publications U. S. Geological Survey: Sixteenth Annual Report, Part II, p. 547; Eighteenth, Part IV, p. 194; Nineteenth, Part IV, p. 337; Twentieth, Part IV, p. 304; Bulletins No. 131, p. 32; No. 140, p. 123. For earlier history and description see Vol. XVII, Tenth Census, p. 56; also Eighth Biennial Report of State Engineer of Colorado, p. 21; and Artesian and Underflow Investigations, Ex. Doc. No. 222, Fifty-first Congress, first session, and Ex. Doc. 53, Parts 1 and 2, Fifty-first Congress, second session.

Estimated monthly discharge of Frenchman River at Palisade, Nebr.

[Drainage area, 1,032 square miles.]

Month.	Mean.	Total.	Run-off.	
			Per square mile.	Depth.
1895.	*Sec.-feet.*	*Acre-feet.*	*Sec.-feet.*	*Inches.*
April	137	8,152	0.13	0.14
May	129	7,932	.13	.15
June	117	6,962	.11	.12
July	99	6,087	.10	.12
August	78	4,796	.08	.09
September	74	4,403	.07	.08
	106	38,430	.10	.70
1896.				
May	114	7,010	.11	.13
June	104	6,188	.10	.11
July	94	5,780	.09	.10
August	76	4,673	.07	.08
September	82	4,879	.08	.09
October	83	5,103	.08	.09
	92	33,488	.09	.60

NORTH AND SOUTH FORKS OF REPUBLICAN RIVER AT BENKELMAN, NEBR.

These stations are fully described in the reports to which reference has already been made in connection with the Kansas Basin. They are located upon the two forks of Republican River, near Benkelman, Nebr., about 20 miles east of the Colorado line.

The channel is in each case sandy and shifting, and frequent changes in the rating tables are necessary. Both stations were established in November, 1894, and were maintained only until the fall of 1895, when they were discontinued owing to the unsatisfactory nature of the results. A few gagings have since been made, which are included in the list of miscellaneous measurements below, page 69.

Estimated monthly discharge of North Fork Republican River at Benkelman, Nebr.

[Altitude, 2,968 feet; drainage area, about 4,900 square miles.]

Month.	Mean.	Total.
1895.	*Second-feet.*	*Acre-feet.*
March	78	4,796
April	59	3,511
May	25	1,537
June	155	9,223
July	124	7,379
August	34	2,091
September	Dry.	0

MISCELLANEOUS GAGINGS IN THE KANSAS RIVER BASIN.

In the following table are given the results of gagings of streams in the Kansas River Basin made during several years by hydrographers acting under the direction of the United States Geological Survey.

Miscellaneous gagings in the Kansas River Basin.

Stream.	Locality.	Date.	Hydrographer.	Discharge.
				Sec.-ft.
Chief Creek	5 miles below Robb, Colo.	Mar. 23, 1891	L. R. Hope	20
North Fork Republican River.	6 miles below Robb, Colo.	do	do	21
Do	3 miles below Wray, Colo.	Apr. 24, 1891	do	51
Do	At State line	do	do	70
South Fork Republican River.	2½ miles west of State line.	Apr. 26, 1891	do	78
Arikaree Creek	3 miles west of State line.	Apr. 27, 1891	do	14
Frenchman River	Wauneta, Nebr	Aug. 9, 1895	O. V. P. Stout	61
Do	do	Sept. 10, 1895	do	56
Do	do	May 15, 1896	C. E. Crownover	85
Do	do	June 18, 1886	O. V. P. Stout	48
Do	do	July 14, 1896	E. G. Youngfelt	91
Do	do	Aug. 12, 1896	O. V. P. Stout	46
Do	do	Sept. 16, 1896	E. G. Youngfelt	85
Do	do	Oct. 17, 1896	C. E. Crownover	63
Do	Palisade, Nebr	Dec. 8, 1894	O. V. P. Stout	116
Do	do	Mar. 22, 1895	do	100
Do	do	June 5, 1895	do	154
Do	do	July 4, 1895	do	74
Do	do	Aug. 9, 1895	do	68
Do	do	Aug. 10, 1895	do	72
Do	do	May 15, 1896	C. E. Crownover	103
Do	do	June 18, 1896	O. V. P. Stout	51
Do	do	July 15, 1896	E. G. Youngfelt	93
Do	do	Aug. 13, 1896	O. V. P. Stout	64
Do	do	Sept. 16, 1896	E. G. Youngfelt	85
Do	do	Oct. 17, 1896	C. E. Crownover	83
North Fork Republican River.	Benkelman, Nebr	Dec. 9, 1894	O. V. P. Stout	75
Do	do	Mar. 23, 1895	do	72
Do	do	June 4, 1895	do	141
Do	do	June 24, 1895	do	36
Do	do	Aug. 7, 1895	do	64
Do	7 miles west of Benkelman, Nebr	June 16, 1896	do	88
Do	Benkelman, Nebr	do	do	29
Do	do	Aug. 25, 1896	E. G. Youngfelt	0

Miscellaneous gagings in the Kansas River Basin—Continued.

Stream.	Locality.	Date.	Hydrographer.	Discharge.
				Sec.-ft.
South Fork Republican River.	Benkelman, Nebr.	Dec. 9, 1894	O. V. P. Stout	1
Do	do	Mar. 23, 1895	do	41
Do	do	June 4, 1895	do	348
Do	do	June 24, 1895	do	75
Do	do	July 3, 1895	do	278
Do	do	Aug. 7, 1895	do	22
Do	do	June 16, 1895	E. G. Youngfelt	3
Do	do	Aug. 18, 1900	O. V. P. Stout	3
North Fork Republican River.	do	do	do	42
Frenchman River	Wauneta, Nebr	July 27, 1900	A. B. McCoskey	74
Do	Palisade, Nebr	do	do	91

ARKANSAS RIVER DIVISION.

DRAINAGE.

The drainage basin of Arkansas River has been so fully described in other reports[a] that but a brief description of its physical character is necessary at this time. The river rises a little west of the center of the State, near Leadville, and flows southerly and westerly until it passes into Kansas, a short distance above Coolidge. Until Canyon is reached the country passed through is in general rather mountainous and comparatively little irrigation is practiced, the water being used mainly for power, for domestic supply, and for placer mining, and here and there only for irrigation in a small way. At Canyon, however, the valley becomes broader, and when the river reaches Pueblo it enters the broad plains of eastern Colorado, upon which the irrigation practiced is limited only by the amount of water available.

The territory drained by the Arkansas and its tributaries forms irrigation division No. II,[b] which is subdivided into a number of water districts. These are district No. 11,[c] at the head of the Arkansas, in which there is but little irrigation and the water is used principally for storage, placer mining, and for the development of power; district

[a] See Hayden's reports, and publications of the U. S. Geological Survey as follows: Tenth Annual Report, Part II, pp. 69 and 86; Eleventh, Part II, pp. 45 and 300; Thirteenth, Part III, p. 362; Seventeenth, Part II, p. 557; Eighteenth, Part IV, p. 223; Nineteenth, Part IV, p. 351; Twentieth, Part IV, p. 323; Twenty-first, Part IV, p. 229; Bulletin No. 131, p. 34; No. 140, p. 153; Water-Supply and Irrigation Paper No. 37, p. 225; No. 59, p. 319. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97.

[b] Fourth Biennial Report Colorado State Engineer. Part I, p. 46; for map see Fourth Biennial Report, Part II, Plate I; Seventh Biennial Report, the same. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 97.

[c] For map see Pl. I in Part II of Fourth and Seventh and Pl. II in Part II of Fifth Biennial Report of State Engineers.

No. 12,[a] the Canyon district, where irrigation is extensively practiced, both upon the main stream and upon its tributaries; district No. 14,[a] the Pueblo district, where the larger canals begin to divert the water of the main stream; district No. 17,[a] the Rockyford district, in which irrigation is very extensively practiced, the largest canals in the State having their headgates in this district, and district No. 67,[b] where the waters are entirely used for irrigation, enormous canals and reservoirs diverting the total flow during the greater portion of the year. The districts comprising the territories drained by the more important of the tributaries are as follows:

District No. 10,[c] comprising the drainage basin of Fontaine Qui Bouille; No. 13,[d] comprising the drainage basin of Grape Creek; No. 15,[e] of the St. Charles; No. 16,[f] of the Huerfano and Cucharas; No. 18,[b] the Apishapa; No. 19,[b] the Purgatory, and No. 66, in which a little irrigation is practiced upon the tributaries of the Dry Cimarron.

District No. 49,[g] in which are the headwaters of the South Fork of the Republican, can hardly be classed with any of the divisions, as it is not of the drainage basin either of the South Platte or of the Arkansas, but lies between the two, and comprises, with No. 65, the headwaters of the Kansas. Of the various tributaries of the Arkansas, those which enter the stream above Pueblo may be classed as mountain streams, while those entering below that city have more of the nature of streams of the plains, although several of them, as the Huerfano, the Apishapa, and the Purgatory, head in the mountains.[h] As is the case in the South Platte drainage, the mountain streams are perennial in nature, although there is a very high stage in the spring and early summer and a very low stage in the fall and winter. The plains streams are nearly always dry, except after storms and for comparatively short distances near their heads, where the water is generally used for irrigation. Although by far the greater portion of the water of the Arkansas is used, there are still opportunities for storage, especially along some of the plains streams. If water is to be stored, however, such canals must be constructed as will safely divert great quantities of water for short durations of time, and convey them to large reservoirs in the plains, where there are many sinks or depressions available. A number of reservoirs have been segregated

[a] For map see Pl. I in Part II of Fourth and Seventh and Pl. II in Part II of Fifth Biennial Reports of State Engineers.

[b] For map see Pl. I in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[c] For map see Pls. I and IX of Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[d] For map see Pl, I in Part II of Fourth and Seventh Biennial Reports of State Engineers.

[e] For map see Pls. I and XI in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[f] For map see Pls. I and XII in Part II of Fourth and Seventh and Pl. IV in Part II of Fifth Biennial Reports of State Engineers.

[g] See page 69.

[h] For thorough investigation of the plains region see Seventeenth Annual Report U. S. Geological Survey, Part II, p. 557.

in this basin by the General Government, but no careful surveys have been made of any of them, excepting a few at the head of the Arkansas.[a] The principal reservoirs of this division now in use are Twin Lakes[b] reservoir (see figs. 2, 3, and 4), which is being used by the Twin Lakes Land and Water Company, and the reservoirs of the Great Plains Water Company, the latter being located about 12 miles north of Lamar in great natural depressions[c] (see fig. 6).

The agriculture of the Arkansas River, as well as of the South Platte, is exceedingly varied, on the upper portions only hay and grain being cultivated, while throughout its middle and lower courses fruit is extensively raised, and lower down melons, sugar beets, and alfalfa are among the staples. Horse, cattle, and sheep raising are extensively practiced throughout the division.

STREAM MEASUREMENTS.

Stations have been maintained upon the main stream and its tributaries in the division for longer or shorter periods of time at Twin Lakes, Granite, Salida, Canyon, Pueblo, Nepesta, Manzanola, Rocky-

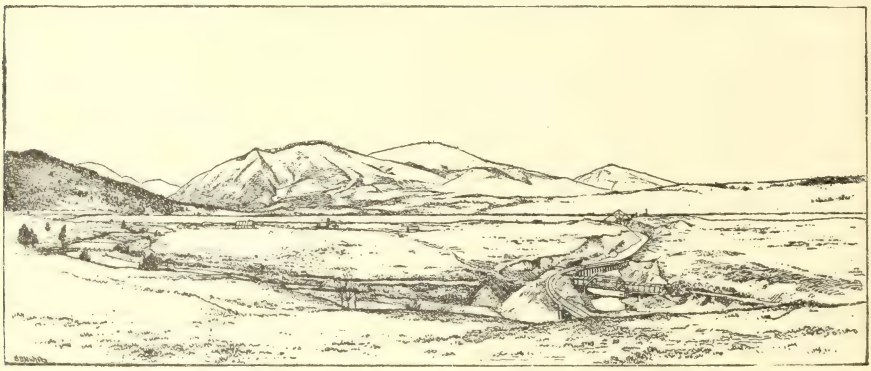


Fig. 2.—Sketch showing original outlet and artificial channel from Twin Lakes.

ford, La Junta, Las Animas, Prowers, Lamar, Granada, upon the main stream, and at Trinidad, J. J. ranch, and Las Animas on the Purgatory. Of the stations named those at Manzanola, La Junta, Las Animas, and Granada are unimportant, so far as this compilation is concerned, as the results obtained have not been of sufficient value to warrant the deduction of any conclusions from them. Those at J. J. ranch and Las Animas on the Purgatory are also omitted for the same reason. The measurements made at these points, however, will be found in the list of miscellaneous measurements (p. 99).

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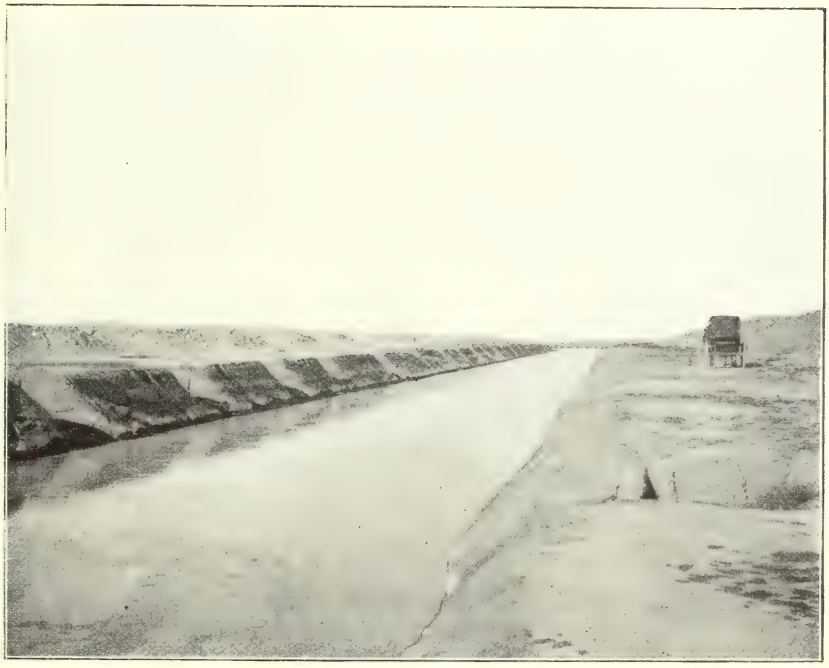
[a] See Annual Reports U. S. Geological Survey: Tenth, Part II, p. 58; Eleventh, Part II, p. 133; Twelfth, Part II, p. 55; Thirteenth, Part III, pp. 362–370; Twentieth, Part IV, p. 31.

[b] See Annual Reports U. S. Geological Survey: Tenth, Part II, p. 95; Eleventh, Part II, p. 135; Thirteenth, Part III, pp. 365 and 460; Nineteenth, Part IV, p. 352; Twentieth, Part IV, p. 323, and Twenty-first, Part IV, p. 238.

[c] For descriptions see Reports last cited; also Twenty-first Annual Report, Part IV, p. 240.

A. QUEEN RESERVOIR DAM, NORTH OF LAMAR.



B. KICKING BIRD CANAL, NORTH OF LAMAR.

LAKE CREEK AT TWIN LAKES.

Lake Creek enters the Arkansas a short distance above the town of Granite. It is not a large stream, but it is of considerable importance owing to the fact that within its basin lie the Twin Lakes, used as reservoirs by the Twin Lakes Land and Water Company. No regular measurements have been maintained upon this stream, those that are given being derived from various sources and made in various places. The present stations are two in number, one between the two lakes, known as

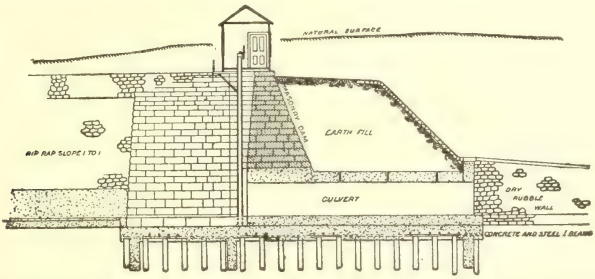


Fig. 3.—Longitudinal section through gates, dam, and culvert of Twin Lakes reservoir.

the Interlaken Station, and one below the lower lake, known as the Lower Twin Lakes Station. Measurements may be made at either station at low water by wading, but at high water advantage may be taken of bridges constructed across the stream. The channel at the Interlaken station is good, but this station must necessarily be abandoned as soon as the water is raised above what was the highwater mark before the construction of the dam described in the Twenty-first Annual Report, Part IV. At the

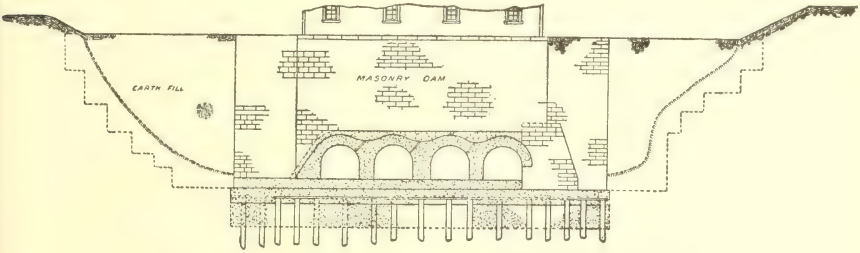


Fig. 4.—Cross section below masonry dam of Twin Lakes reservoir.

lower station the channel is rocky, but fairly permanent in its nature, and the banks are high and not liable to overflow.

The importance of the stations lies in the facts that the data obtained will furnish information concerning available power and will be of especial value in determining the amount of water to which the Twin Lakes Land and Water Company is entitled at its head gates. The waters of this stream are also largely used in placer mining.[a]

[a] For more detailed data concerning these stations, see Tenth Biennial Report of the State Engineers of Colorado, p. 293, and publications of the U. S. Geological Survey, as follows: Eleventh Annual Report, Part II, pp. 47 and 96; Twelfth, Part II, Pl. LXVI, opposite p. 240; Twenty-first, Part IV p. 238; Water-Supply and Irrigation Papers No. 37, p. 256; No. 39, p. 449; and No. 50, p. 320.

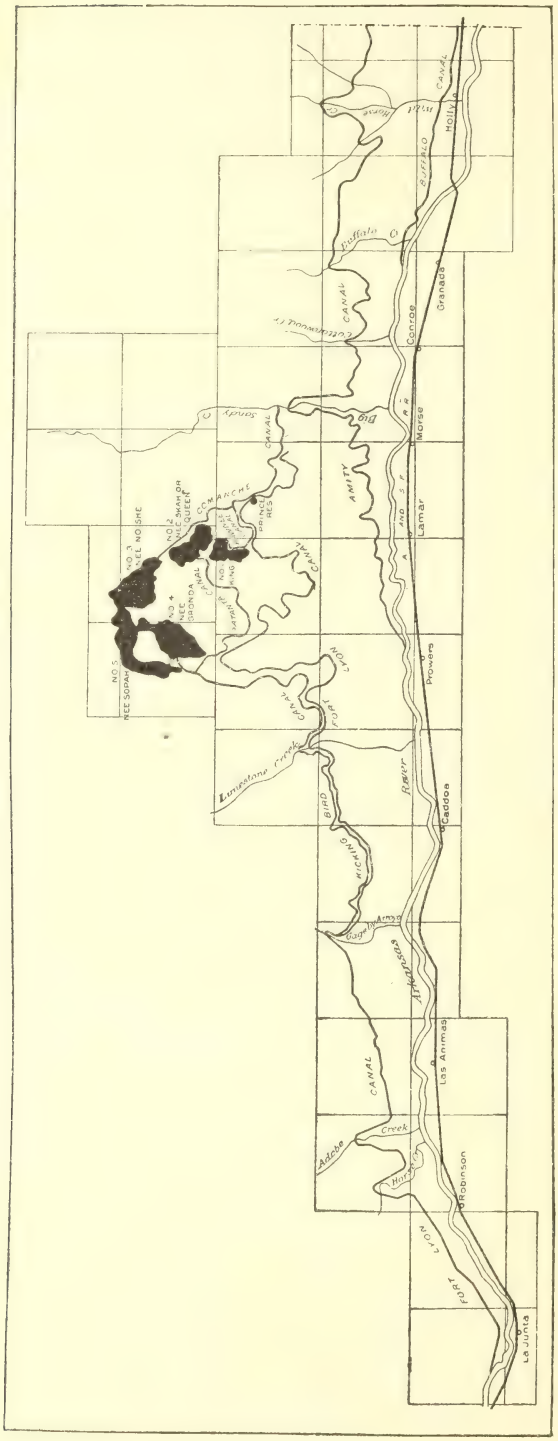


Fig. 5.—Irrigation system of the Great Plains Water Company.

Estimated monthly discharge of Lake Creek at Twin Lakes.

[Altitude, 9,012 feet; drainage area below both lakes, 109 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
June 21 to 30			847	50,519	7.79	8.69
July	667	370	454	27,915	4.17	4.81
August	588	230	381	23,427	3.50	4.04
September 1 to 11			194	11,543	1.78	1.99
July 22 to 31			206	4,086	1.89	.79
August	182	40	119	7,317	1.09	1.26
September 1 to 8			35	555	.32	.10

Discharge measurements made on Lake Creek at Twin Lakes.

Date.	Hydrographer.	Gage height.	Discharge.	Remarks.
1899.		*Feet.*	*Sec.-ft.*	
July 17	A. L. Fellows	2.80	273	At old station No. 1. (Station in channel above upper lake.)
Oct. 12	do	1.90	27	
1899.				
June 21	O. O. McReynolds	3.60	1,007	At old station No. 2. (Station at bridge over channel between lakes.)
July 17	A. L. Fellows	1.90	374	
Oct. 12	do	1.40	42	
1900.				
July 9	A. L. Fellows	1.70	203	
July 16	O. O. McReynolds	1.00	146	
1900.				
July 10	A. L. Fellows	.85	248	Interlaken Station. (Station at head of channel between lakes.)
July 18	do	.50	122	
Aug. 3	O. O. McReynolds	.25	52	
Sept. 4	C. W. Beach	.15	25	
1899.				
June 21	O. O. McReynolds	3.80	1,208	Old station No. 3. (Station at head of channel discharging from lower lake.)
June 27	do	3.20	696	
July 17	A. L. Fellows	2.55	391	
July 24	O. O. McReynolds	2.50	344	
Aug. 14	do	2.50	183	
Oct. 13	A. L. Fellows		22	
1900.				
July 10	A. L. Fellows	2.50	193	
July 16	O. O. McReynolds	2.40	245	Lower Twin Lakes Station. (Station below junction of old channel and new cut discharging from lake.)
July 18	A. L. Fellows	2.35	210	
July 18	do	2.50	260	
July 18	do	1.97	118	
Aug. 11	O. O. McReynolds	2.13	156	
Sept. 4	C. W. Beach	1.30	25	

ARKANSAS RIVER AT GRANITE

This station was located at the wagon bridge across the Arkansas at Granite, measurements being made from this bridge. The results are not of great value, owing to the extremely changeable nature of the channel, which lies in beds of bowlders and gravel and shifts constantly. For that reason measurements and records have not been kept up closely. The present condition of the channel seems to be somewhat more stable, however, and the station may be reopened. It is important from the fact that the discharge of the entire upper portion of the Arkansas, which is of the most value for the development of power and for placer mining, may be learned from the data obtained at this point.[a]

Estimated monthly discharge of Arkansas River at Granite.

[Altitude, 8,930 feet; drainage area, 425 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per sqare mile.	Depth in inches.
1897.						
May	2,058	268	1,109	68,190	2.61	3.01
June	2,162	923	1,459	86,817	3.43	3.83
July	1,096	444	719	44,209	1.69	1.95
August	546	176	350	21,520	.82	.94
September	350	114	169	10,057	.40	.45
October	114	114	114	7,009	.27	.31
November			[b] 115	6,843	.27	.30
December			[b] 115	7,071	.27	.31
1898.						
August	151	75	113	6,948	.27	.31
September	93	8	45	2,678	.11	.12

[a] For more detailed information concerning this station see Biennial Reports of the State Engineer of Colorado: Eighth, p. 484; Ninth, p. 359; Tenth, p. 296. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, pp. 47 and 96; Nineteenth, Part IV, p. 353; Twentieth, Part IV, p. 330; Water-Supply and Irrigation Papers, No. 16, p. 117; No. 28, pp. 110, 116, and 117; No. 37, p. 257; No. 39, p. 449. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 104.

[b] Approximate.

Discharge measurements made on Arkansas River at Granite.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
July 3	A. P. Davis	0.50	1,065
Sept. 26	do	3.10	215
1897.			
Apr. 17	C. C. Babb	3.20	120
May 8	F. Cogswell	4.20	940
May 18	do	4.90	1,236
June 29	do	4.60	1,151
July 27	do	3.75	415
Aug. 31	do	3.20	206
Sept. 27	do	3.10	203
Nov. 6	do	3.00	153
1898.			
July 30	A. L. Fellows	3.50	151
Aug. 26	do	3.40	112
Oct. 26	do	3.30	75
1899.			
May 25	do	5.00	1,476
July 15	do	2.80	1,178
Oct. 14	do	1.60	130
1900.			
July 9	do	.....	570

ARKANSAS RIVER AT SALIDA.

This station is located at the footbridge near the railroad shops at Salida. It was established April 11, 1895, and has been maintained for a portion of each year since that time. The gage rod has been fastened to the north side of the footbridge, but considerable difficulty has been experienced owing to the fact that ice and logs constantly interfere with the rod, three new rods having been required in 1900. The banks are high and are not subject to overflow, but there are large bowlders in the stream which interfere with the accuracy of the results of measurements.

The importance of the maintenance of the station lies in the information furnished as to the time required for water to flow from Granite to Salida and again from Salida to Canyon, this question having a bearing upon the distribution of the use of the water turned out from Twin Lakes; and it is, moreover, valuable from the point of view that it is extremely probable that the entire discharge of the Arkansas at this point may eventually be used for power purposes in the Grand Canyon of the Arkansas.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 480; Ninth, p. 361; Tenth, p. 298. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 224; Nineteenth, Part IV, p. 355; Twentieth, Part IV, p. 331, Twenty-first, Part IV, p. 230. Bulletin No. 140, p. 155; Water-Supply and Irrigation Papers, No. 16, p. 118; No. 28, pp. 110 116, and 117; No. 37, p. 258; No. 39, p. 450; and No. 50, p. 322. Also report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 104.

Discharge of Arkansas River at Salida.

[Altitude, 7,035 feet; drainage area, 1,160 square miles.]

Month.	1895.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Run-off.[a] Second-feet per square miles.	Run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
March	.....	.....	.....	[b] 308	.....	[c] 308	18,938	0.27	0.31
April	[d] 1,117	.....	.....	398	155	557	33,143	.48	.54
May	1,545	1,646	.....	1,352	1,790	1,583	97,335	1.36	1.57
June	1,599	1,839	.....	2,639	2,083	2,040	121,388	1.76	1.96
July	1,159	985	.....	1,301	633	1,020	62,717	.88	1.01
August	860	518	280	497	320	495	30,436	.43	.49
September	537	397	199	281	291	341	20,291	.29	.32
October	402	289	223	.....	192	277	17,032	.24	.28
November	.....	.....	267	.....	.....	[c] 267	15,888	.23	.26
Mean	1,031	946	242	968	780	765	417,168	0.66	6.74
Acre-feet for period recorded	416,976	345,184	58,560	370,560	331,058	.....	.....	.....	.....

[a] The run-off for acre-feet given is for that part of each year covered by the observations (and estimates) given, and for a thirty-day month at the rate given as the mean for the whole period of each year covered, while the discharge is for average months and the total for an average nine months from March to November, inclusive, as calculated from the observations and estimates. Details may be found in the authorities cited.

[b] March 22 to 31, inclusive.

[c] One year only, but approximately correct.

[d] April 11 to 30, inclusive.

Maximum and minimum discharge and average run-off of Arkansas River at Salida for that portion of each year covered by records.

Year.	Discharge.				Run-off.	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Oct. 13	402	May 14	2,462	0.99	0.89
1897	Oct. 4	320	May 31	2,910	.91	.82
1898	Oct. 7	100	Aug. 2	428	.23	.21
1899	Sept. 28	240	June 20	3,900	.92	.83
1900	Apr. 14	65	June 1	3,633	.74	.67

Discharge measurements made on Arkansas River at Salida.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
Sept. 27	A. P. Davis	0.60	463
1896.			
May 26	T. Cogswell	3.10	[a] 2,023
June 24	do	1.40	638
Sept. 29	do	1.00	352
Oct. 27	do	.80	317
1897.			
Apr. 17	C. C. Babb	.69	219
Apr. 27	F. Cogswell	1.55	709
May 8	do	2.20	1,178
May 30	do	4.05	2,821
June 29	do	2.50	1,492
July 27	do	1.35	606
Aug. 31	do	.85	371
Sept. 27	do	1.00	405
Nov. 6	do	.90	378
1898.			
Apr. 27	A. L. Fellows	1.10	480
May 20	do	3.10	445
June 25	do	3.10	2,352
July 29	do	1.25	568
Aug. 26	do	.90	360
Oct. 26	do	.80	222

[a] Approximate; meter out of order.

Discharge measurements made on Arkansas River at Salida—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 26	A. L. Fellows	1.72	686
May 25	do	3.10	1,999
July 14	do	2.40	1,801
Nov. 18	do	.80	317
1900.			
Mar. 15	A. L. Fellows	.90	271
June 14	do	4.30	3,036
Aug. 8	do	1.08	443
Aug. 22	do	.87½	364

ARKANSAS RIVER AT CANYON.

This station is located near the Hot Springs Hotel, 1½ miles west of Canyon, and a short distance below the mouth of Grape Creek (see Pl. VII). It was established in the year 1889, and records have been kept up ever since that time, thus furnishing a most valuable table of discharge of the Arkansas River. The station is of particular importance as it is located at the mouth of the canyon and above practically all the irrigating ditches excepting the Canyon ditch and the South Canyon ditch, which draw their supplies at short distances above the station. Each of these carries from a very few feet up to 60 cubic feet per second, according to need during the irrigation season.

The table does not include the amounts carried by the canals, and their flow should be added to the discharge of the river at the station in order to get the total run-off at the mouth of the canyon. The channel is fairly constant, changing but little during the entire tim that the station has been maintained. The banks are high and not subject to overflow.[a]

[a] For more detailed data concerning this station, see Biennial Reports of the State Engineers of Colorado: Fourth, Part I, p. 62, and Part II, Pl. XVI; Fifth, Part I, pp. 21 and 38, and Part II, Pl. X; Sixth, pp. 19 and 24; Seventh, pp. 163 and 164; Eighth, p. 474; Ninth, p. 363; Tenth, p. 300. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, p. 97; Twelfth, Part II, pp. 240 and 349; Thirteenth, Part III, pp. 19 and 363; Fourteenth, Part II, p. 106; Eighteenth, Part IV, p. 225; Nineteenth, Part IV, p. 356; Twentieth, Part IV, p. 331; Twenty-first, Part IV, p. 231; Bulletins, No. 131, p. 35; No. 140, p. 156; Water-Supply and Irrigation Papers, No. 11, p. 60; No. 16, p. 119; No. 28, pp. 110, 116, and 117; No. 37, p. 258; No. 39, p. 450; No. 50, p. 323. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 112.

A. ARKANSAS RIVER AT CANYON.

B. DIVERTING DAM ON ARKANSAS RIVER AT CANYON.

Discharge of Arkansas River at Canyon.

[Altitude, 5,363 feet; drainage area, 3,060 square miles.]

Month.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	[b] 400	[b] 300	310	431	496	505	445	344	454	[b] 380	[b] 270	316	345	384	23,611	0.12	0.14
February	[b] 500	[b] 300	363	474	493	533	420	361	438	[b] 380	[b] 350	328	353	407	22,604	.13	.14
March	[b] 600	[b] 300	320	586	524	555	505	471	472	[b] 380	338	584	439	467	28,715	.15	.17
April	[b] 1,000	300	477	857	522	568	627	868	558	320	393	544	736	598	35,583	.20	.22
May	1,440	600	2,090	2,012	1,241	1,480	1,960	1,566	1,276	1,741	909	1,924	2,251	1,512	96,658	.51	.59
June	2,090	1,374	2,611	3,291	2,787	3,115	2,704	1,900	959	2,464	2,428	3,496	3,492	2,516	149,712	.82	.91
July	1,350	602	1,571	1,468	1,798	1,069	1,393	1,413	538	1,115	1,613	2,021	891	1,296	79,688	.42	.48
August	932	340	670	951	769	563	710	1,095	395	553	326	711	273	638	39,229	.21	.24
September	605	220	519	473	435	477	551	635	313	366	189	225	211	401	23,861	.13	.14
October	[b] 500	223	531	624	511	[b] 50	294	505	285	471	228	236	241	396	24,349	.14	.16
November	[b] 500	299	522	498	527	[b] 500	260	499	267	519	302	440	266	415	24,694	.13	.14
December	[b] 400	335	502	476	561	428	268	444	579	[b] 400	[b] 350	336	298	414	25,456	.14	.16
Mean[c]	860	433	874	1,012	889	857	845	837	544	757	640	930	816	792	574,160	0.25	3.49
Acre-feet[c]	632,105	313,153	634,453	733,588	645,320	620,477	612,584	607,507	393,624	549,322	464,559	673,279	590,452	.....	.....	.....	.....

[a] The run-off in acre-foot given is for each entire year, including estimated months; the discharge given is for average months, and the tables for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

[b] Approximate.

[c] For entire year.

Maximum and minimum discharge and average run-off of Arkansas River at Canyon for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1888	Sept. 28	420	June 19	2,760	3.80	0.28
1889	Oct. 12	190	Aug. 9	2,620	1.92	.14
1890	Jan. 14	180	May 28	3,270	3.88	.28
1891	Jan. 11	325	June 13	4,230	4.49	.35
1892	Jan. 15	345	June 25	4,750	3.95	.29
1893	Aug.	200	June	4,750	3.80	.27
1894	Oct.	245	June	4,400	3.74	.28
1895	Dec. 16	256	June 11	2,588	3.71	.27
1896	Nov. 28	124	Aug. 30	2,876	2.41	.18
1897	Apr. 10	108	June 4	3,452	3.33	.25
1898	Oct. 3	160	June 19	3,245	2.84	.21
1899	Feb. 18	160	June 20	4,432	3.98	.30
1900	Sept. 22	194	May 29	4,251	3.50	.26

[a] The run-off given is for each entire year, including estimated months. Details may be found in the authorities cited.

Discharge measurements made on Arkansas River at Canyon.

Date.	Hydrographer.	Gage height.	Discharge.
1889.		*Feet.*	*Sec.-ft.*
July 26	Robert Robertson	2.25	421
July 26	do	3.00	833
1890.			
Apr. 1	Robert Robertson	1.62	222
Apr. 2	do	1.70	286
Apr. 3	do	1.88	360
Apr. 28	do	2.93	744
May 1	do	2.73	775
May 2	do	2.80	891
May 2	do	2.78	862
May 23	do	4.77	2,705
June 5	do	4.85	2,641
June 12	do	4.53	2,220
June 14	do	4.65	2,598
June 19	do	4.48	2,380
June 23	do	4.55	2,386
June 27	do	4.55	2,394
June 30	do	4.23	2,055
July 9	do	4.22	1,998
July 12	do	4.05	1,806
July 16	do	3.82	1,546

Discharge measurements made on Arkansas River at Canyon.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1891.		*Feet.*	*Sec.-ft.*
Apr. 13	T. M. Bannon	3.00	777
Dec. 4	do	1.85	328
1893.			
Sept. 22	F. H. Newell	2.45	291
1894.			
Apr. 15	F. H. Newell	4.20	2,395
May 18	do	3.80	1,940
June 18	do	4.80	2,387
Sept. 20	A. P. Davis	2.65	395
Oct. 15	do	2.40	319
1895.			
May 31	A. P. Davis	4.35	2,434
June 13	do	4.50	2,397
Oct. 4	do	2.70	585
1896.			
July 31	F. Cogswell	2.40	414
Aug. 30	do	2.00	203
Sept. 16	do	2.05	251
Oct. 31	do	2.20	289
Nov. 14	do	2.55	294
1897.			
Apr. 16	C. C. Babb	2.20	260
May 7	do	3.10	827
May 26	F. Cogswell	4.95	2,712
June 16	do	5.25	3,071
July 14	do	3.60	1,140
Aug. 11	do	3.05	744
Nov. 5	do	2.98	540
1898.			
May 21	A. L. Fellows	3.05	608
June 25	do	4.82	2,830
July 28	do	3.05	611
Oct. 27	do	2.60	316
1899.			
Apr. 27	A. L. Fellows	3.20	611
May 26	do	4.55	2,189
July 7	do	4.50	2,651
Aug. 18	do	2.90	553
Nov. 7	do	2.55	306
1900.			
Mar. 14	A. L. Fellows	2.85	408
June 14	do	5.50	3,235
July 20	do	2.85	570
Sept. 8	do	2.10	229
Sept. 12	R. W. Hawley	2.10	205

ARKANSAS RIVER AT PUEBLO.

The first records of the discharge of Arkansas River in the vicinity of Pueblo are for the months of May and June, 1885. From this time until August, 1889, records were kept more or less irregularly at a point near the mouth of the canyon, about 9 miles above the city of Pueblo. No other records were kept in this vicinity until September, 1894, when the station was relocated in the city of Pueblo. As only one large ditch, the Bessemer canal, takes water from the river in District No. 14, in which Pueblo is situated, the station answers admirably for assisting in the distribution of the waters of that district. Owing, however, to the changes in the channel, the construction of side walls, and the removal of a dam in the lower part of the city, it has been necessary to change the location of the rod from time to time. Up to the fall of 1898 the records of gage heights were taken from a rod situated at the north end of the Santa Fe avenue bridge; at that time, however, another rod was placed at the south end of the Main street bridge, and in March, 1900, another rod was placed at a point a short distance below the south end of the Union avenue bridge. This is the rod used at present. These changes in location have, however, no material bearing upon the actual discharge, as measurements have been taken frequently and these stations are practically one, being located in the same long stretch of clear, open channel, with no inflow, and having high retaining levees constructed by the city. (See Pl. VII, *B*.) The channel at present is probably the best in the State, although it fills to some extent at low water and scours out again at high stages. Measurements are usually made from the Main street bridge, but may be made by wading at low water.

In comparing the tables it should be borne in mind that the records for 1885 to 1889, inclusive, are for a point about 9 miles above the station for the later years, and that considerable water is taken out between the two points. Moreover, much less water was used on the higher reaches of the stream prior to 1889 than since that time, so that practically the two stations bear little relationship to each other. They are, however, given together for advantage in comparison. Measurements of the water level are kept up regularly by the office of the city engineer of Pueblo, and it is to this office that we are indebted for a large proportion of the records given in the tables.

This station is of particular importance, for, being near the head of one of the most important districts and also near the headquarters of the superintendent of the Arkansas division, it is of use in ascertaining the discharge of the river with reference to the proper distribution of the water amongst consumers. It is further important because the waters of the Arkansas are being used more and more for power, and

A. ARKANSAS RIVER BELOW MAIN STREET BRIDGE, PUEBLO.

B. ARKANSAS RIVER NEAR ROCKYFORD.

the surplus, whenever there is any, is being stored in large reservoirs, of which there are several important ones in the vicinity of Pueblo.[a]

Discharge of Arkansas River at canyon above Pueblo, 1885 to 1889, inclusive.

Month.	1885.	1886.	1887.	1889.	Average.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
May	1,069	3,046	.....	1,300	1,805
June	3,187	5,569	3,477	2,108	3,585
July	.....	1,724	3,352	766	1,947
August	.....	1,481	1,717	668	1,289
September	.....	1,372	1,129	.....	1,250

[a] For more detailed data concerning this station, see Biennial Reports of the State Engineers of Colorado: Third, pp. 168 to 174; Fourth, Part I, p. 62, and Part II, Pl. XVI; Eighth, p. 468; Ninth, p. 366; Tenth, p. 304. Also publications U. S. Geological Survey: Eleventh Annual Report, Part II, pp. 49 and 98; Eighteenth, Part IV, p. 227; Nineteenth, Part IV, p. 357; Twentieth, Part IV, p. 336; Twenty-first, Part IV, p. 232; Bulletin No. 140, p. 158; Water-Supply and Irrigation Papers, No. 11, p. 61; No. 16, p. 120; No. 28, pp. 111, 116, and 117; No. 37, p. 259; No. 39, p. 450; No. 50, p. 325. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

Estimated mean discharge of Arkansas River at Pueblo.

[Altitude, 4,690 feet; drainage area, 4,600 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	460	519	328	330	407	411	409	25,148	0.09	0.10
February	476	456	335	385	603	418	446	24,770	.10	.11
March	357	396	213	320	406	391	347	21,336	.08	.09
April	744	470	241	370	418	822	510	30,347	.11	.12
May	1,561	1,101	1,674	841	1,683	2,997	1,643	101,024	.36	.41
June	2,152	895	2,213	2,202	3,384	4,006	2,475	147,273	.54	.60
July	1,900	633	1,041	1,605	2,043	878	1,350	83,008	.29	.33
August	1,275	489	467	306	811	314	610	37,507	.13	.15
September	494	309	272	125	238	232	278	16,542	.07	.08
October	551	293	413	210	303	321	349	21,459	.08	.09
November	530	314	484	309	374	338	392	23,325	.09	.10
December	462	333	356	363	327	396	373	22,935	.09	.10
Mean	914	517	670	614	916	960	765	554,674	.17	2.28
Acre-feet, total	663,419	375,960	485,818	444,664	663,839	694,960	.....	.....	.....	.....

[a] The run-off given is for average months, and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Maximum and minimum discharge and average run-off of Arkansas River at Pueblo for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Dec. 26	256	June 13	2,588	2.72	0.20
1896	Aug. 10	203	Aug. 18	3,428	1.54	.11
1897	Mar. 13	146	June 2	3,750	1.98	.14
1898	Oct. 6	31	July 13	5,385	1.82	.13
1899	Sept. 13	150	June 20	4,891	2.73	.20
1900	Sept. 1	134	June 2	6,980	2.80	.21

[a] The run-off given is for each year entire, including estimated months; the discharge given is for average months, and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Discharge measurements made on Arkansas River at Pueblo.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Apr. 24	P. J. Preston	[a]	322
Sept. 19	A. P. Davis	0.35	378
Oct. 13	do	.39	370
1895.			
Feb 6	A. P. Davis	.40	411
May 20	do	1.65	1,435
June 3	do	[b]	2,261
June 4	do	[c]	1,973
June 4	do	[d]	2,022
June 11	do	2.80	2,758
Sept. 5	F. Cogswell	.70	570
1896.			
Mar. 22	F. Cogswell	.50	470
Apr. 8	do	1.30	1,016
May 27	do	2.00	1,682
June 5	do	1.65	1,403
July 10	do	.30	335
July 30	do	.50	510
Aug. 18	do	[e] .00	203
Aug. 19	do	.85	534
Aug. 19	do	10.00	16,500
Sept. 16	do	.30	294
Oct. 30	do	.35	320
Nov. 13	C. C. Babb	.31	298

[a] Measurement made at Main Street bridge.
[b] Measurement made at Swallows.
[c] Measurements made at Bridge No. 3, section 4.
[d] Measurements made at Bridge 155 B.
[e] Approximate estimate of flood at 12 m. night of August 18, 1896. A maximum velocity of 15 feet per second was obtained by means of floats.

Discharge measurements made on Arkansas River at Pueblo—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
		Feet.	*Sec.-ft.*
1897.			
Apr. 16	C. C. Babb	0.20	216
May 6	F. Cogswell	1.00	799
May 21	do	2.00	1,856
June 18	do	2.55	2,219
July 16	do	1.15	981
Aug. 10	do	.95	805
Sept. 8	P. J. Preston	.10	184
Sept. 28	do	.45	394
Nov. 4	F. Cogswell	.75	601
1898.			
Apr. 5	P. J. Preston	.27	248
Apr. 29	A. L. Fellows	.06	513
May 5	C. W. Beach	.09	876
May 30	do	.10	1,144
June 3	do	1.40	1,639
June 9	A. L. Fellows	1.8	2,002
June 14	C. W. Beach	1.9	1,987
July 8	do	1.63	1,726
July 26	A. L. Fellows	[a] .85	816
July 28	C. W. Beach	[a] .81	743
Aug. 2	do	.45	405
Aug. 11	do	.50	468
Aug. 20	C. W. Beach, R. W. Hawley	.15	211
Aug. 30	A. L. Fellows	.00	134
Oct. 20	C. W. Beach	.20	290
Oct. 29	A. L. Fellows	.40	320
Nov. 3	C. W. Beach	.30	344
1899.			
Apr. 27	A. L. Fellows	.80	695
May 26	do	2.20	2,221
June 3	C. W. Beach	2.55	2,856
June 17	do	3.60	4,565
July 1	do	2.22	2,959
July 8	A. L. Fellows	1.61	2,098
Aug. 1	C. W. Beach	.72	1,199
Aug. 5	do	1.46	1,938
Aug. 14	A. L. Fellows	1.20	1,496
Sept. 10	do	.50	180
Sept. 18	C. W. Beach	.10	388
Oct. 6	do	.20	331
Nov. 7	A. L. Fellows	.05	411

[a] New gage rod at Main street.

Discharge measurements made on Arkansas River at Pueblo—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1900.		*Feet.*	*Sec.-ft.*
Mar. 3	A. L. Fellows	2.17	498
Mar. 16	do	2.05	435
Apr. 8	do	2.34	675
Apr. 12	C. W. Beach	2.15	608
May 21	do	5.70	5,072
June 13	A. L. Fellows	5.10	3,963
July 17	do	2.50	751
July 21	do	2.25	583
Sept. 3	R. W. Hawley	1.35	153
Sept. 5	C. W. Beach	1.43	191
Sept. 7	A. L. Fellows	1.40	174
Sept. 25	C. W. Beach	1.82	346

ARKANSAS RIVER AT NEPESTA.

This station is located at the wagon bridge a short distance above the railroad station of the Atchison, Topeka and Santa Fe Railroad at Nepesta, and is maintained by the Great Plains Water Company. It was established September 8, 1897, and records have been kept during each irrigation season since that time, only those for 1898, 1899, and 1900 being reliable, however. Two gage rods are necessary; one for use at high and the other at low water. Measurements are made from the wagon bridge. The channel is sandy and shifting and frequent changes are necessary in the rating table. The importance of the station is due to the fact that it is so conveniently located to the railroad station that representatives of the large irrigation canals upon the river may readily keep themselves informed as to the discharge and the use of the water of the stream.[a]

[a] For further information concerning this station, see Biennial Reports of the State Engineers of Colorado: Ninth, p. 370; Tenth, p. 308. Also publications U. S. Geological Survey: Nineteenth Annual Report, Part IV, p 358: Twentieth, Part IV, p. 337; Twenty-first, Part IV, p. 233, Bulletin No. 131, p. 37; Water-Supply and Irrigation Papers, No. 16, p. 121; No. 28, pp. 112, 116, and 117; No. 37, p. 260; No. 39, p. 450; No. 50, p. 326. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 124.

Estimated monthly discharge of Arkansas River at Nepesta.

[Altitude, 4,364 feet; drainage area, 9,130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
May	2,055	350	1,116	68,621	0.12	0.14
June	3,665	918	2,103	125,137	.23	.26
July	4,125	136	1,310	80,549	.14	.16
August	697	127	311	19,123	.03	.03
September	294	160	232	13,805	.03	.03
October	511	160	279	17,155	.03	.03
November	511	260	366	21,778	.04	.04
	.....	.....	817	346,168	.09	.69
1899.						
May	2,246	259	1,154	70,957	.13	.15
June	3,882	1,156	2,622	156,020	.29	.32
July	6,066	610	2,651	163,004	.29	.33
August	6,974	172	957	58,844	.10	.12
September	285	154	200	11,901	.02	.02
October	314	172	235	14,450	.03	.03
November	2,791	191	350	20,826	.04	.04
	.....	.....	1,167	495,002	.13	1.00
1900.						
May	9,600	4,246	5,876	361,301	.64	.74
June	7,782	4,064	5,498	327,154	.60	.67
July	3,700	427	1,699	104,467	.19	.22
August	1,519	172	422	25,948	.05	.06
September	427	172	262	15,590	.03	.03
October	610	314	435	26,747	.05	.06
November	792	259	514	30,585	.06	.07
	.....	.....	2,101	891,792	.23	1.85

Discharge measurements made on Arkansas River at Nepesta.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
May 31	F. H. Newell		[a]30,000
June 1	do		12,000
June 2	do		8,000
1897.			
Sept. 8	P. J. Preston	2.00	168
Sept. 30	do	2.34	281
1898.			
Apr. 27	P. J. Preston	2.55	360
May 6	C. W. Beach	3.05	746
May 10	do	4.25	1,998
June 6	do	3.43	1,060
July 28	do	3.25	573
Aug. 20	do	2.85	247
Nov. 6	do	2.93	212
1899.			
May 29	A. L. Fellows	4.60	1,810
June 7	C. W. Beach	4.63	1,636
Aug. 3	do	4.00	610
Aug. 25	do	3.10	215
Oct. 2	do	3.12	213
1900.			
Apr. 12	C. W. Beach	4.30	1,101
Sept. 8	R. W. Hawley	3.70	146

[a] Estimated.

ARKANSAS RIVER AT ROCKYFORD.

This station is located at the wagon bridge crossing the Arkansas River, at a point about 2 miles northeast of the town of Rockyford. It was established May 3, 1897, by Mr. S. W. Cressy, water commissioner of district No. 17, having his headquarters at Rockyford, for his convenience and information in distributing the waters of his district. Mr. Cressy maintained this station as long as he remained in charge of the office to April 7, 1900. The river is straight for a long distance above and below the bridge, but the channel is wide and the bed is sandy and very shifting, so that few measurements were made. Results must be considered as approximate.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Ninth, p. 374; Tenth, p. 310. Publications U. S. Geological Survey: Nineteenth Annual Reports, Part IV, p. 353; Twentieth, Part IV, p. 338; Twenty-first, Part IV, p. 234; Water-Supply and Irrigation Papers, No. 16, p. 122; No. 28, pp. 112, 116, and 117; No. 37, p. 261; No. 39, p. 450; No. 50, p. 327. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 124.

For description of Laguna Canal, in this district, see Twentieth Annual Report, Part IV, p. 339.

Estimated monthly discharge of Arkansas River at Rockyford.

[Altitude, 4,177 feet; drainage area, 11,440 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May 3 to 31	3,363	64	1,147	70,527	0.100	0.120
June	3,206	628	1,834	109,130	.160	.180
July	2,034	41	589	32,216	.052	.060
August	3,676	20	614	37,754	.054	.062
September	108	13	41	2,440	.004	.004
October	393	27	143	8,793	.013	.015
November	550	41	155	9,223	.014	.016
December[a]			50	3,074	.044	.051
1898.						
January			[a]75	[a]4,612	.007	.008
February 20 to 28	193	34	75	4,165	.01	.01
March	393	129	254	15,618	.02	.03
April	550	64	213	12,674	.02	.02
May	3,832	108	1,206	74,155	.12	.13
June	3,284	315	2,047	121,805	.18	.20
July	3,754	193	1,249	76,799	.11	.13
August	706	108	269	16,540	.02	.03
September	393	64	157	9,342	.01	.02
October	550	84	246	15,126	.02	.03
November	862	84	530	31,537	.05	.05
December	393	84	228	14,020	.02	.02
The year	3,832	34	546	396,393	.04	.68
1899.						
March 13 to 31	570	140	309	19,000	.027	.031
April	520	140	274	16,304	.024	.027
May	1,270	140	732	45,009	.064	.074
June	2,710	770	1,498	89,137	.131	.146
July	3,020	270	1,504	92,478	.131	.150
August	3,570	105	686	42,181	.060	.069
September	420	95	153	9,104	.013	.014
October	300	55	145	8,916	.013	.015
November	1,070	105	280	16,661	.024	.027
December 1 to 9	190	115	148	9,100	.013	.015
1900.						
January 16 to 31	470	190	319	19,061	.027	.031
February, 13 days	470	270	410	22,770	.036	.037
March	450	190	324	19,922	.028	.032
April 1 to 7	3,120	360	1,283	76,344	.112	.125

[a] Approximate.

Discharge measurements made on Arkansas River at Rockyford.

Date.	Hydrographer.	Gage height.	Discharge.
1897.		*Feet.*	*Sec.-feet.*
Sept. 29	P. J. Preston	0.37	140
1898.			
Apr. 17	P. J. Preston	.90	237
May 27	C. W. Beach	1.83	1,692
1899.			
May 30	A. L. Fellows	1.88	1,042
Oct. 16	do	.88	136

ARKANSAS RIVER AT PROWERS.

This station is located at the dam constructed across the Arkansas River at the headgate of the Colorado and Kansas canal, this point being selected in September, 1899, in the hope that the channel might prove permanent, but no records were kept until the spring of 1900. The rating curve obtained at this point from gagings made thus far gives excellent results within the limits of the measurements. There being no bridge at the station, measurements can be made only at the lower stages of the river. The station is of particular importance, owing to the fact that it is located near the head of irrigation district No. 67, and may therefore be used in the regulation of the use of the waters of the Arkansas in that district.[a]

Estimated monthly discharge of Arkansas River at Prowers.

[Altitude, 3,677 feet; drainage area, 19,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
April 15 to 30	7,140	1,060	2,940	174,942	0.155	0.173
May	5,860	2,660	3,398	208,935	.178	.238
June	4,900	742	2,617	155,722	.138	.154
July	1,700	2	161	9,990	.008	.009
August	445	0	45	2,767	.002	.002
September [b]	30	0	6	357	.000	.000
October [b]			6	369	.000	.000
November [b]	16	4	8	476	.000	.000
December	41	4	18	1,107	.001	.001

[a] For more detailed information regarding this station, see Tenth Biennial Report of the State Engineers of Colorado, p. 312; Water-Supply and Irrigation Papers, U. S. Geological Survey, No. 37, p. 263, and No. 50, p. 328; also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

[b] Estimated.

Discharge measurements made on Arkansas River at Prowers.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Sept. 8	A. L. Fellows	0.20	16
1900.			
July 5	C. W. Beach	.60	304
July 19	A. L. Fellows	.38	113
July 28	C. W. Beach	.77½	546

ARKANSAS RIVER NEAR LAMAR.

The greater proportion of the records of this locality are those kept by the Amity Canal Company, their headgate being at a point 7 miles west of Lamar, on the north side of the river, the headgate keeper making a daily record of the discharge both in the river and the canal. (See Pl. IX.) There is a dam across the river at this point for the diversion of water into the Amity canal, but owing to the unevenness of its crest, to the fact that timbers and driftwood lodge upon it, and to other causes, the results are not entirely reliable. Few measurements have been made except in the canal. For a short time in the year 1899 estimates were made at the wagon bridge north of Lamar by the water commissioner of district No. 67. These are of interest as giving approximately an idea of the flow of the water for the time covered, and are therefore presented in a separate table.

The principal value of hydrographic data at this point is with reference to the storage of water in reservoirs, of which those of the Great Plains Water Company, described in the Twenty-first Annual Report, Part IV, p. 240, are located, 12 miles north of the town of Lamar.[a]

[a] For further information concerning this station, see Biennial Reports of the State Engineers of Colorado; Ninth, p. 379; Tenth, p. 314. Also publications United States Geological Survey: Eleventh Annual Report, Part II, pp. 49 and 51; Twentieth, Part IV, pp. 324 and 340; Water-Supply and Irrigation Papers, No. 28, p. 114; No. 37, p. 263; No. 50, p. 329. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 126.

A. DAM OF AMITY CANAL ON ARKANSAS RIVER.

B. HEAD GATE OF AMITY CANAL.

Discharge of Arkansas River near Lamar.

[Altitude, 3,592 feet.]

AT HEAD OF AMITY CANAL, AS FURNISHED BY E. R. BANNISTER, HEADGATE KEEPER.

Month.	1898.		1899.		1900.	
	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.	Second-feet.	Acre-feet.
January					239	14,696
February					280	11,552
March					170	10,453
April					2,973	176,906
May					4,469	274,788
June			655	38,975	3,290	195,769
July			1,870	114,982	280	17,217
August	211	12,974	884	54,355	89	5,472
September	23	1,369	74	4,403	22	1,309
October	54	3,320	87	5,349	20	1,230
November	265	15,769	249	14,817	109	6,486
December	248	15,249	131	8,055	[a] 150	9,223

[a] Approximate.

AT LAMAR BRIDGE,[a] ESTIMATED BY J. B. TRAXLER, WATER COMMISSIONER, DISTRICT NO. 67.

Day.	1899.		
	March.	April.	May.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*
1	3,000	40	12
2	4,000	40	12
3	4,000	35	12
4	2,500	35	12
5	2,000	30	12
6	1,500	25	12
7	1,200	25	12
8	1,000	25	12
9	800	20	12
10	800	15	12
11	1,500	16	12
12	1,500	16	12
13	1,200	15	12
14	1,000	18	14
15	1,000	20	15½
16	1,000	15	5
17	1,000	15	5
18	800	15	5
19	400	15	5

[a] Total amount of water in district March 13, 250 second-feet; April 3, 225 second-feet; April 16, 175 second-feet; April 25, 120 second-feet; April 30, 75 second-feet; May 5, 180 second-feet; May 10, 100 second-feet; May 13, 200 second-feet; May 14, 150 second-feet; May 16, 230 second-feet; May 18, 325 second-feet; May 20, 308 second-feet.

Discharge of Arkansas River near Lamar—Continued.

AT LAMAR BRIDGE, ESTIMATED BY J. B. TRAXLER, WATER COMMISSIONER, DISTRICT NO. 67—Continued.

Day.	1899.		
	March.	April.	May.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*
20	300	15	5
21	300	15	.....
22	200	15	.....
23	150	15	.....
24	100	15	.....
25	75	15	.....
26	50	15	.....
27	40	12	.....
28	35	12	.....
29	35	12	.....
30	35	12	.....
31	40	.....	.....

Discharge measurements made on Arkansas River at Lamar.

Date.	Hydrographer.	Discharge.	Remarks.
1889.		*Sec.-ft.*	
May 26	F. H. Newell	300	At Lamar.
July 19	do	15,000	Do.
July 22	do	851	Do.
Aug. 3	do	284	Do.
Aug. 7	do	187	Do.
1899.			
May 31	A. L. Fellows	249	At Amity canal.
June 18	do	114	Do.
1900.			
Apr. 7	do	8,890	At Lamar.

PURGATORY RIVER AT TRINIDAD.

This station was located May 1, 1896, in the town of Trinidad, the gage rod being attached to the cylindrical pier at the west end of the Las Animas Street bridge. The station was, however, discontinued July 31, 1899, the greater portion of the water of the river being taken out at points above the station, and the channel being shifting and the results unreliable. A more favorable location would be at a point about 9 miles above the town, near the mouth of the canyon, and above where the most of the water is taken out for irrigation. A station at this point would also have the added advantage that it would furnish

data concerning the flow that might be used for storage, as there are important reservoir sites situated above this point.[a]

Estimated monthly discharge of Purgatory River at Trinidad.

[Altitude, 5,990 feet; drainage area, 742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1896.						
May	113	45	67	4,120	0.09	0.10
June	780	0	60	3,570	.08	.09
July	4,600	8	342	21,029	.46	.53
August	1,657	0	76	4,673	.10	.12
September	554	0	73	4,344	.10	.11
October	189	18	71	4,366	.10	.12
November	60	25	35	2,083	.05	.06
December			[b] 40	2,460	.05	.06
1897.						
January			[b] 40	2,459	.05	.06
February			[b] 50	2,777	.07	.07
March			[b] 50	3,074	.07	.08
April	327	68	165	9,818	.22	.24
May	1,412	327	731	44,947	.99	1.14
June	1,534	189	403	23,980	.54	.60
July	1,657	30	250	15,372	.34	.39
August	2,023	10	282	17,339	.38	.44
September	386	30	97	5,772	.13	.14
October	104	54	60	3,689	.08	.09
November	54	30	42	2,499	.06	.07
December			[b] 35	2,152	.05	.06
1898.						
May	882	109	264	16,233	.36	.41
June	1,282	109	377	24,433	.51	.57
July	1,147	81	259	15,925	.35	.40
August	752	42	181	11,129	.24	.28
September	1,282	42	173	10,294	.23	.26
October	58	31	39	2,398	.05	.06
November	42	36	39	2,321	.05	.06
1899.						
April	193	32	82	4,879	.11	.12
May	230	52	110	6,764	.15	.17
June	492	4	71	4,225	.10	.11
July	2,362	16	443	27,239	.60	.69

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineer of Colorado: Eighth, p. 460; Ninth, p. 381; Tenth, p. 319. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 231; Nineteenth, Part IV, p. 358; Twentieth, Part IV, p. 340; Twenty-first, Part IV, p. 235; Water-Supply and Irrigation Papers, No. 16, p. 123; No. 28, pp. 113, 116, and 117; No. 37, p. 263; No. 39, p. 450. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 119.

[b] Estimated.

Discharge measurements made on Purgatory River at Trinidad.

Date.	Hydrographer.	Gage height.	Discharge.
		Feet.	*Sec.-ft.*
1895.			
Sept. 24	A. P. Davis		86
1896.			
Apr. 27	F. Cogswell	3.20	88
June 4	do	3.15	72
July 11	do	3.20	66
Sept. 14	do	3.50	30
Oct. 12	do	3.70	48
Nov. 16	C. C. Babb	3.60	24
1897.			
May 22	F. Cogswell	4.25	677
June 17	do	4.10	386
July 15	do	3.90	189
Sept. 23	P. J. Preston	3.60	49
Nov. 13	F. Cogswell	3.55	46
1898.			
Apr. 28	A. L. Fellows	3.90	150
July 27	do	3.90	149
Aug. 29	do	3.60	45
Aug. 6	C. W. Beach	3.76	101
Oct. 28	A. L. Fellows	3.40	31
1899.			
Apr. 28	do	3.60	52
July 12	do	3.30	4

MISCELLANEOUS GAGINGS.

A number of miscellaneous gagings have been made at different times at different points upon the Arkansas and its tributaries, which have been compiled, so far as they are obtainable, from the various sources already cited, and are presented in the following table. Stations have not been maintained at the points mentioned, or if maintained at all have been irregularly kept, and the records have been so unsatisfactory that it is thought best not to publish the gage heights or to approximate the discharge, the data necessary for computing the rating tables being insufficient.

Miscellaneous discharge measurements, Arkansas River and tributaries.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
				Sec.-ft.
Sept. 26, 1893	F. H. Newell	Arkansas	Byron	0
Sept. 24, 1894	A. P. Davis	do	Hayden	114
Sept. 29, 1897	P. J. Preston	do	Manzanola	208
May 18, 1898	C. W. Beach	do	do	847
June 13, 1898	do	Purgatory	J. J. ranch	37
Aug. 5, 1898	do	do	do	60
Sept. 15, 1898	do	Arkansas	Manzanola	208

Discharge measurements made on Arkansas River at La Junta.

Date.	Hydrographer.	Discharge.
1893.		*Sec.-ft.*
Sept. 27	F. H. Newell	24
1894.		
May 21	F. H. Newell	157
June 7	do	15,000
June 8	do	9,500
Oct. 5	do	55
1895.		
Feb. 6	F. H. Newell	182
May 19	do	658
Dec. 2	do	455
1897.		
Sept. 12	P. J. Preston	0
1899.		
May 30	A. L. Fellows	246
June 13	do	857
June 20	do	1,181

Discharge of Arkansas River at La Junta.

[Drainage area, 12,200 square miles.]

Month.	Discharge.			Total for month.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1889.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
May 20 to 31	1,960	605	1,089	66,973	0.09	0.10
June	2,620	825	1,355	80,622	.11	.12
July	2,290	345	844	51,906	.07	.08
August	1,630	55	435	26,752	.04	.04

SEEPAGE MEASUREMENTS ON ARKANSAS RIVER.

A series of seepage measurements have been made upon Arkansas River for the purpose of determining the return flow. These have been carried on under the direction of Prof. L. G. Carpenter, of Fort Collins, who has published a bulletin upon the subject.

The table below is compiled from data given in the Ninth Biennial Report, page 308, of the State engineer's office of Colorado, as furnished by Professor Carpenter:

Seepage measurements of Arkansas River.

[In second-feet.]

Place.	Distance (miles).	1897.		1898.	
		Gain.	Loss.	Gain.	Loss.
Canyon to Bessemer ditch	33	54.40	.....	55.17	.....
Bessemer to Pueblo	10	.....	42.18	.....	15.96
Pueblo to Orchard Grove	8	.....	9.40	19.41	.....
Orchard Grove to Boone	16	103.47	.....	20.30	.....
Boone to Nepesta	10	40.44	.....	.....	17.65
Nepesta to Otero canal	8	.....	5.78	.....	11.00
Otero canal to Apishapa Creek	7	16.90	.....	18.15	.....
Apishapa Creek to Rockyford	16½	30.55	.....	21.21	.....
Rockyford to Fort Lyon canal	9	35.59	.....	22.39	.....
Fort Lyon canal to La Junta	3	13.04	.....	8.20	.....
La Junta to Jones ditch	11	10.85	.....	14.76	.....
Jones ditch to Las Animas	9	28.51	.....	20.08	.....
Las Animas to Fort Lyon	6	38.14	.....	13.26	.....
Fort Lyon to Caddoa	11	3.63	.....	.....	.16
Caddoa to Amity canal	10	.....	.....	.....	6.64
Amity to Lamar	11	.....	.....	6.68	.....
Lamar to Holly	30	13.21	.....	14.20	.....
Holly to Coolidge, Kans	7	.....	.....	0	.....
Total	215	387.43	57.36	243.81	51.41
Unreliable		57.36	.....	51.41	.....
Gain		330.07	.....	192.40	.....

NOTE.—Counting the unreliable measurement to gain as in 1898, the gain in 1897 would be 250 second-feet.

RIO GRANDE DIVISION.

DRAINAGE.

Descriptions of the Rio Grande drainage have been given in former reports, but a short résumé is here presented for the convenience of those who do not care to look up the former records.[a]

The Rio Grande and its tributaries drain the mountainous area south and east of the Continental Divide in southwestern Colorado, the principal streams flowing from the east side of the Needle Mountains and from the south and east side of the San Juan Range. Important streams also flow from La Garita Mountains in Saguache and Mineral counties. The main stream flows in an easterly direction for about 75 miles, receiving numerous tributaries from the mountainous region through which it flows. At the town of Del Norte the valley broadens into what is known as the San Luis Valley; thence the stream flows southeastward and southward for about the same distance to a point about 20 miles southeast of Antonito, where it crosses the State line. From the time the river leaves Del Norte but few streams of importance flow into it, as nearly all of those that issue from the mountains lose their waters in the plains before they reach the main stream. This is particularly true of the drainage north and east of the river from the Cochetopa Hills and the Sangre de Cristo Range. Although the streams flowing from these mountains are very numerous and carry large volumes of water, yet they furnish no source of supply to the Rio Grande itself, all the water being lost either in the sands or in broad, shallow lakes, until Trinchera Creek, flowing through the Costilla land grant, is reached. This stream, although usually dry, furnishes a supply at different times in the year. On the south and west side of the river, however, many important streams flow from the mountains, which in their higher stages carry large volumes of water to the Rio Grande. Among these are the Alamosa, La Jara, and Conejos. The supply from these streams also is used mostly during summer, so that after the flood stages are past very little water flows from any of these sources into the Rio Grande itself, as most of it is used in the upper part of the valley, and in the late summer very little passes Alamosa, below which place there are but few irrigating canals. During the flood stages, however, great volumes of water

[a] Hayden's Report of 1875, pp. 153 to 167. Publications U. S. Geological Survey: Tenth Annual Report, Part II, p. 65; Eleventh, Part II (see index); Twelfth, Part II, p. 240; Thirteenth, Part III (see index); Fourteenth, Part II, p. 110; Eighteenth, Part IV, p. 245; Nineteenth, Part IV, p. 381; Twentieth, Part IV, p. 355. Bulletins No. 131, p. 41; No. 140, p. 169; Water-Supply and Irrigation Paper No. 37. See also all Biennial Reports of the State Engineers of Colorado for irrigation in this division, and Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 127. For maps see Pl. I of Part II of the fourth and seventh and Pl. V of the fifth report. See also Senate Document No. 229, Fifty-fifth Congress, second session, on the "Equitable distribution of the waters of the Rio Grande."

flow in the Rio Grande itself and several of its tributaries which might be stored and used for the extension of the irrigated area. Farming is carried on extensively among the upper valleys of several of the streams issuing from the mountains north and east of San Luis Valley, but no official measurements have been made upon any of these streams.

On the headwaters of nearly all of the tributaries of the Rio Grande, as well as on the main stream itself, are important reservoir sites, which might be utilized to store water for late use, so as to render crop raising more certain than it is now. Unfortunately, owing to international complications, it has been impossible in the past to make use of these sites, but it is hoped that this restriction will soon be removed, as it is clearly to the advantage of the agricultural interests as a whole that the water should be used to as great an extent as possible along the upper portion of the streams.

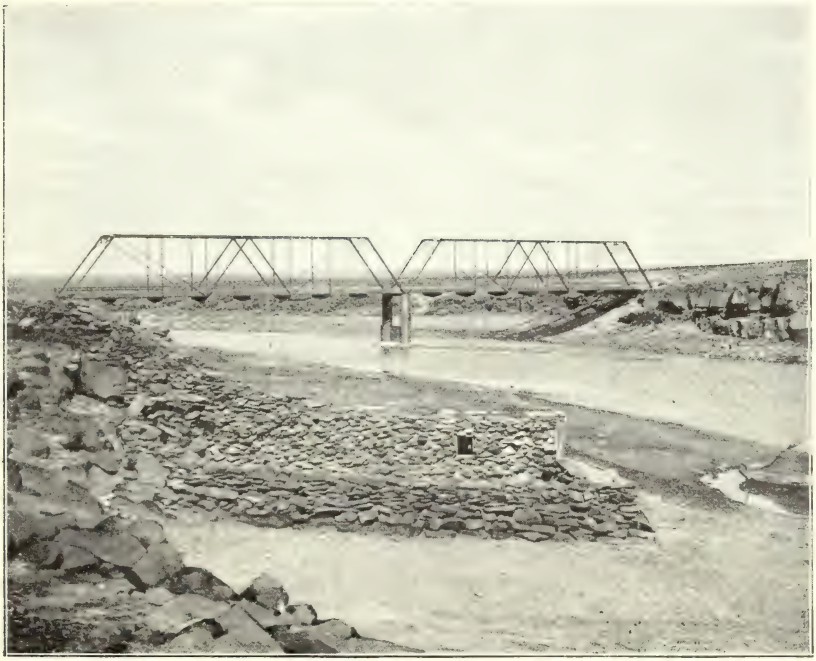
The lands drained by the Rio Grande and its tributaries constitute irrigation division No. III. The various districts into which it is divided are No. 20, comprising the Rio Grande drainage, excepting those streams included in separate districts, which are No. 21, covering Alamosa and La Jara creeks with their tributaries; No. 22, Conejos Creek; No. 24, Costilla Creek; No. 25, San Luis Creek; No. 26, Saguache Creek; No. 27, Tuttle, Carnero, La Garita, and all other creeks and their tributaries which have their sources of water supply in the La Garita Mountains and flow eastward into the San Luis Valley; and No. 35, Trinchera Creek.

There are many problems of interest connected with the use of water in the San Luis Valley, among which is the study of loss by evaporation and seepage. Investigation is being carried on in this line by Prof. L. G. Carpenter, already mentioned, of the Colorado State Agricultural College.

STREAM MEASUREMENTS.

Although hydrographic data are most desirable in this valley, but little hydrographic work has been done, owing to the scarcity of funds, both in the office of the State engineer and the United States Geological Survey, so that only three stations have been maintained for any considerable length of time, and of these only one, the station at Del Norte, has been maintained for a length of time sufficient to furnish anything like accurate information concerning the normal flow. The two that have been kept up for shorter periods are a station near the State line, upon the main Rio Grande, and one upon the Conejos, about 10 miles west of the town of Antonito, on the Denver and Rio Grande Railroad.

A. GAGING RIO GRANDE AT DEL NORTE.



B. STATE BRIDGE ACROSS RIO GRANDE NEAR COLORADO STATE LINE.

RIO GRANDE AT DEL NORTE.

This station is located about 3 miles west of the town of Del Norte, above the main canals taking water from the Rio Grande. Records have been kept since the fall of the year 1889 for very nearly the entire time. A steel cable is stretched across the river at this point and the gagings are made by means of a car traveling on the cable, distances being marked on a tag wire, and, at low water, by wading. The channel consists of small bowlders and gravel, and although the sides are not high, the stream has never been known to overflow at this point. The conditions are excellent for good results, as the bed of the stream scours but little, although the fall is comparatively rapid. The station is of great value, as the distribution of water among the numerous consumers is made to depend very largely upon the data obtained as shown on the gage rod. Information is also furnished concerning the supply available for storage in reservoir sites above.

The citizens of San Luis Valley seem to appreciate fully the advantage of this station and have frequently expressed themselves as desiring to see this service extended.[a]

[a] For detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 21 and 40; and Part II, Pl. V; Sixth, p. 38; Seventh, p. 170; Eighth, p. 488; Ninth, p. 385; Tenth, p. 321. Also publications U. S. Geological Survey, Eleventh Annual Report, Part II, pp. 53 and 98; Twelfth, Part II, p. 246; Thirteenth, Part III, p. 99; Fourteenth, Part II, p. 110; Eighteenth, Part IV, p. 246; Nineteenth, p. 383; Twentieth, p. 359; Twenty-first, Part IV, p. 256; Bulletins No. 131, p. 41; Nos. 140 to 170; Water-Supply and Irrigation Papers, No. 11, p. 64; No. 16, p. 127 No. 28, pp. 126, 129, and 130; No. 37, p. 277; No. 39, p. 450; No. 50, p. 347. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 113, 127

Discharge of Rio Grande at Del Norte.

[Altitude, 7,865 feet; drainage area, 1,430 square miles.]

Month.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Mean run-off[a]		
														Equivalent in acre-feet.	Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
January	.....	[b] 552	[b] 990	[c] 300	[b] 966	[b] 1,003	[b] 801	[b] 1,293	[bc] 1,000	[bc] 1,377	[b] 1,308	[b] 862	[b] 950	58,413	0.68	0.78
February	.....	[b] 796	[b] 1,294	[c] 300	[bc] 700	[b] 995	[b] 953	[b] 1,258	[bc] 1,000	[bc] 1,472	[b] 1,113	[b] 1,005	[b] 989	54,926	.71	.83
March	.....	487	1,280	316	[bc] 500	[b] 831	638	[b] 1,081	[bc] 1,000	[bc] 1,471	[b] 875	399	[b] 807	49,620	.58	.67
April	.....	913	[b] 1,410	1,047	533	699	[b] 1,885	1,484	1,067	[b] 1,912	617	419	[b] 1,089	64,800	.78	.87
May	.....	4,331	3,285	2,605	1,944	1,798	2,116	2,374	3,537	2,722	1,378	2,854	2,631	161,774	1.88	2.17
June	.....	3,807	4,146	2,187	1,749	802	2,209	821	3,391	4,390	1,091	2,691	2,480	147,570	1.77	1.97
July	.....	1,515	1,693	740	395	292	958	463	1,108	1,643	703	547	908	55,830	.65	.75
August	.....	612	663	444	324	309	729	261	475	509	598	231	467	28,715	.33	.38
September	.....	383	527	263	270	286	454	477	631	319	365	256	384	22,850	.27	.30
October	[c] 278	470	844	259	263	289	435	469	1,472	259	492	343	489	30,067	.35	.40
November	319	478	374	360	278	236	353	310	665	[b] 816	490	253	411	24,456	.29	.32
December	281	[b] 565	[c] 325	[b] 922	[b] 642	288	[b] 1,008	375	[bc] 800	[bc] 1,300	[b] 742	[b] 755	[b] 666	40,950	.48	.55
Mean	292	[b] 1,242	1,403	812	[b] 714	[b] 652	[b] 1,044	[b] 884	1,346	[b] 1,517	814	[b] 884	[b] 1,023	739,971	.73	9.99
Acre-feet, total	.....	900,926	1,014,426	590,219	516,886	471,408	754,931	641,017	945,418	1,094,950	589,293	641,017	.....	.....	.....	.....

[a] The run-off given is for average months and the totals for an average year as calculated from all observations and estimates. Details may be found in the authorities cited.

[b] Probably too high because of ice piling up along the sides of the stream and thus narrowing the channel. It is not likely that the winter flow is even more than 600 second-feet. The totals are carried out, however, as though the observations gave a correct idea of the discharge.

[c] Approximate.

Maximum and minimum discharge and average run-off of Rio Grande at Del Norte for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1890	Oct. 2	307	Apr. 27	5,930	12.06	0.89
1891	Sept. 19	290	May 7	5,650	13.56	1.00
1892	Sept. 26	243	May 24	4,710	7.92	.58
1893	Nov. 8	214	May 19	3,320	6.93	.51
1894	Nov. 27	201	May 17	2,850	6.29	.46
1895	Nov. 21	322	June 12	3,840	10.14	.75
1896	Aug. 21	214	May 3	3,579	8.58	.63
1897	Sept. 1	342	May 27	5,234	13.05	.96
1898	Nov. 9	221	June 3	5,266	14.06	1.08
1899	Sept. 13	268	May 11	2,330	7.87	.58
1900	Aug. 31	163	May 29	5,454	8.55	.63

[a] The run-off, per acre-foot, given is for each entire year, including estimates; the discharge given is for average months and the totals for an average year, as calculated from all observations and estimates. Details may be found in the authorities cited.

Discharge measurements made on Rio Grande at Del Norte.

Date	Hydrographer.	Gage height.	Discharge.
1891.		*Feet.*	*Sec.-ft.*
Apr. 10	T. M. Bannon	2.20	527
1892.			
Oct. 27	T. M. Bannon	1.58	274
1894.			
June 13	F. H. Newell	2.68	968
Sept. 27	A. P. Davis	1.52	267
1895.			
June 14	A. P. Davis and F. Cogswell	4.00	2,818
Oct. 13	F. Cogswell	1.80	414
1896.			
June 22	F. Cogswell	1.90	492
July 27	do	1.70	385
Sept. 28	do	2.30	706
Oct. 26	do	1.80	445
1897.			
Apr. 26	F. Cogswell	3.00	1,507
May 17	do	4.05	3,014
May 29	do	5.45	4,898
June 28	do	3.30	1,769
July 26	do	2.00	640
Aug. 30	do	1.55	373
Oct. 25	do	2.66	1,113

Discharge measurements made on Rio Grande at Del Norte.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Apr. 14	A. L. Fellows	3.27	1,966
May 18	do	3.23	1,802
June 23	do	5.25	5,181
Aug. 25	do	1.86	521
Oct. 25	do	1.48	244
1899.			
Apr. 25	A. L. Fellows	2.42	1,004
May 24	do	2.92	1,480
June 29	do	2.10	734
Aug. 21	do	1.58	387
1900.			
Mar. 30	A. L. Fellows	1.54	346
May 12	do	3.84	2,441
June 16	do	3.66	2,382
Aug. 18	do	1.34	221

CONEJOS RIVER NEAR LOS MOGOTES.

This stream, the most important tributary of the Rio Grande in Colorado, rises on the eastern slope of the San Juan Range, which forms the western boundary of Conejos County. It flows southeastward as far as the town of Conejos; then, bending northeastward, enters the Rio Grande below the mouth of Trinchera Creek. All of the ordinary flow of this stream is used during the irrigation season, but at flood stages and in winter considerable water goes to waste. The station is located about 10 miles west of Antonito, from which town it may be reached by driving. The nearest post-office is at Los Mogotes, about 4 miles from the station, but the observer was always accustomed to get his mail at Antonito. It was established August 25, 1899, and was first located at a wagon bridge crossing the river; but owing to the fact that the rod at that point was maliciously destroyed, the station was removed to a point about 500 yards downstream, where it was attached to a pier projecting into the river near a farmhouse. The channel is fairly good, being of gravel and not particularly liable to either change or overflow. Owing to the removal of the gage from its old station and to the small number of measurements made, but few data are available.

San Antonio River is an important branch of the Conejos, and a few measurements were made upon this stream also, these being given in the list of miscellaneous measurements.[a]

[a] For more detailed information regarding this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 328, and U. S. Geological Survey Water-Supply and Irrigation Papers, No. 37, p. 278, and No. 30, p. 348. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 105.

Discharge measurements made on Conejos River near Los Mogotes.

[A. L. Fellows, hydrographer.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
August 25	1.00	76
November 28	2.20	70
1900.		
March 28	1.68	144
May 11	3.10	1,087
June 23	2.30	467
August 17	1.15	33

RIO GRANDE AT CENICERO.

This station is located a short distance north of the boundary line between Colorado and New Mexico, at a point where the river is crossed by a State wagon bridge. It was established July 28, 1899, and has been kept up regularly ever since. Two gage rods are necessary, one for high and the other for low water. The channel is excellent, the bed consisting of bowlders and rock and being subject to but little change, and the banks are high and not liable to overflow. At high water gagings may be made from the bridge, but at low water they are usually made by wading. The station is an important one, as it gives information concerning the entire drainage of the Rio Grande in Colorado and the discharge of the river practically where it enters New Mexico, this information being of value to both Colorado and New Mexico and furnishing important data bearing upon storage and the use of water. The nearest railroad point is Antonito, from which the station may be reached by driving about 15 miles. The nearest post-office is at Eastdale, but the observer has been in the habit of getting his mail at Cenicero, which is on the road between Antonito and the gaging station, about 4 miles from the former.[a]

[a] For more detailed information concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 326; U. S. Geological Survey Water-Supply and Irrigation Papers, No. 37, p. 279; No. 39, p. 450, and No. 50, p. 349.

Estimated monthly discharge of Rio Grande at Cenicero.

[Drainage area, 7,695 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
July	170	12	42	2,582	0.005	0.006
August	129	20	53	3,259	.007	.008
September	423	31	102	6,069	.013	.015
October	170	65	117	7,194	.015	.017
November	297	170	259	15,412	.034	.038
December	381	170	318	19,553	.041	.047
Last 6 months of the year	423	12	148	54,069	.019	.131
1900.						
January	1,134	594	638	39,229	.083	.095
February	1,134	22	759	42,153	.099	.103
March	1,134	236	583	35,847	,076	.087
April	504	183	350	20,826	.045	.050
May	3,294	414	1,430	87,927	.186	.214
June	3,294	79	1,424	84,734	.185	.206
July	58	22	29	1,783	.004	.004
August	22	16	22	1,353	.003	.003
September	43	16	31	1,845	.004	.004
October	58	31	31	2,275	.005	.006
November	504	58	155	9,223	.020	.022
December	594	414	571	35,109	.074	.085
The year	3,294	16	502	362,304	.065	.879

Discharge measurements made on Rio Grande at Cenicero.

[A. L. Fellows, hydrographer.]

Date.	Gage height.	Discharge
1899.	*Feet.*	*Sec.-ft.*
June 28	0.90	20
August 24	1.00	31
November 28	1.80	297
1900.		
March 29	1.60	236
May 10	2.00	594
June 22	1.80	420
August 16	.75	18

MISCELLANEOUS MEASUREMENTS.

A table is given below of the miscellaneous measurements of which records are obtainable that have been made in the Rio Grande drainage basin in Colorado. These are of importance, as they furnish information concerning the flow of the various streams at stated times and given points.

Miscellaneous discharge measurements on Rio Grande and tributaries.

Date.	Hydrographer.	Stream.	Locality.	Discharge in second-feet.
Sept. 28, 1894	A. P. Davis	Rio Grande	Alamosa	10
June 16, 1895	F. Cogswell	do	do	1,176
Oct. 14, 1895	do	do	do	92
May 19, 1896	do	do	do	132
June 23, 1896	do	do	do	32
June 24, 1896	F. F. Anderson	Conejos	Los Mogotes	67
July 26, 1896	F. Cogswell	do		3
Aug. 20, 1899	A. L. Fellows	do	6 miles below Alamosa.	17
Aug. 23, 1899	do	do	½ mile above Alamosa.	10
May 11, 1900	do	San Antonio	Antonito	473
June 22, 1900	do	do	do	4

SEEPAGE MEASUREMENTS.

The seepage measurements given below were made under the direction of Prof. L. G. Carpenter, of Fort Collins, and were furnished by him to the State engineer of Colorado. The table is from the Tenth Biennial Report, pages 219 and 221. Professor Carpenter expects to publish a bulletin on these measurements shortly.

Seepage measurements on Rio Grande, 1900.

[In second-feet.]

Place of measurement.	Date.	Section inflow.	Section outtake.	River.	Section gain or loss.	Total gain or loss.
Railroad station at South Fork	Aug. 30	0.85	33.41	194.24		
United States Geological Survey gaging station	Aug. 31			209.83	48.15	48.15
Do	Aug. 20		146.61	249.06		
Above Del Norte canal	do			176.50	25.95	22.20
Do	Aug. 21		32.11	178.90		
At Off's	do			168.48	21.69	43.89
Do	Aug. 22		47.19	156.22		
Below Prairie canal	do	.31		99.29	-10.05	33.84
Do	Aug. 23	4.33	96	108.91		
Below Monte Vista bridge	do			14	—3.24	30.60
Do	Aug. 24		30.29	14.30		
Below San Luis canal	do	5.21	14.24	5.90	21.89	52.49
Below Hickory-Jackson ditch	do			10.65	13.98	66.47
Do	Aug. 25		10.69	11.55		
Below Alamosa	do			1	.14	66.61
Do	Aug. 27			1.01		
Above mouth of Conejos River	do	14.33		1.35	.24	66.85
Below Conejos (North Branch)	do	6.90		15.33	—.35	66.50
Below Las Sauces	do			23.98	1.75	68.25
Do	Aug. 28			22.31		
Above State bridge	do			17.22	—5.09	63.16

Seepage measurements on Conejos River, 1900.

[In second-feet.]

At State gaging station	Aug. 31			24.65		
Above San Juan bridge	do		1.97	24.77	2.09	
At bridge	do		2.15	.50	-22.12	—20.03
Above Cerritos	Aug. 30	0.77		.80	.30	—19.73
Below San Antonio Creek	do		3.32	.55	1.02	—20.75
At McIntire place	do			3.88	6.65	—14.10
Do	Aug. 29		24	4.33		
Below McIntire spring	do		14.19	31.33	3	—11.10
Two hundred feet above bridge	do			24.02	6.88	-4.22

SAN JUAN DIVISION.

IRRIGATION.

San Juan River rises in the San Juan Mountains, the small streams at the head flowing westward, opposite to the direction taken by the branches of the Conejos. The country is generally mountainous and rough, and but little irrigation is practiced along the stream, except in the bottom lands adjacent to the channel. The stream flows but a short distance through Colorado before entering New Mexico, through which it flows for about 100 miles, then crosses the southwest corner of Colorado again, and flows thence through Utah to its junction with the Colorado at Henry Mountain. The principal tributaries flowing from Colorado into this river are the Piedra, Los Pinos, Florida, Las Animas, La Plata, and Mancos, all of which flow through comparatively narrow valleys, crossing the line into New Mexico before the San Juan itself is reached. A large portion of this country has been but very recently opened to settlement, as it remained a part of the Southern Ute Reservation until 1899, when the western half of that reservation was thrown open to settlement, and a number of settlers have come in. A very considerable portion of the most desirable lands had, however, been taken by the Indians in severalty. There are a number of excellent mesas of good farming land which will undoubtedly be eventually irrigated. A number of surveys have already been made of canal lines to cover these tracts, which will be speedily pushed to completion.

DRAINAGE.

San Juan River and its tributaries drain practically all of that portion of the southwestern corner of Colorado which comprises the Durango Land District, except a portion of the northern part, which is drained by the Dolores River, a tributary of the Grand. The northeastern quarter of this district is very mountainous, the principal tributaries of the San Juan having their headwaters among lofty mountain peaks and mountain parks of high altitude. Little irrigation is practiced in the upper valleys of any of the streams of this district, except for raising hay, above a height of about 7,000 feet, from which altitude the level of this district in Colorado runs down to about 4,500 feet. In the lower valleys agriculture is extensively practiced, and nearly all kinds of crops that may be raised in temperate climates are cultivated. A very large portion of the division will undoubtedly be irrigated eventually, and water will be used extensively for the development of power, so that the supply of water in many of the streams will prove inadequate without a comprehensive system of storage. There are fortunately a number of excellent reservoir sites on the headwaters of a number of the streams, particularly upon the San Juan, Piedra, Los Pinos, and Florida.

The drainage area of the San Juan and its tributaries, while constituting irrigation division No. IV in accordance with the laws of Colorado, is practically composed of a number of strictly independent districts, as each one of the main tributaries crosses the line between Colorado and New Mexico before it empties into the San Juan, and hence the use of the water of the various streams does not conflict to any great extent. The irrigation districts that compose the division and the streams that furnish their supply of water are No. 29, comprising the territory drained by the headwaters of the San Juan and the Piedra; No. 31, the Los Pinos district; No. 30, the Las Animas district; No. 33, the La Plata district; No. 34, the Mancos district, and No. 32, the Montezuma Valley district, the latter being practically a part of the Grand River division.[a]

STREAM MEASUREMENTS.

A number of stations have been maintained at different times in this division, those for which separate tables are given being situated near Arboles, on the San Juan and Piedra rivers; at Ignacio, on Los Pinos River; at Stewart's ranch, on Florida River; at Durango, on Animas River; and at Mancos, on Mancos River.[b]

SAN JUAN RIVER AT ARBOLES.

This station is located a short distance west of the old Arboles railroad station on the Denver and Rio Grande Railroad, where a footbridge was constructed by the Survey across the river for the purpose. The channel is not favorable to accurate measurements, the bridge crossing the river at a point where there is a deep hole and the left bank being liable to overflow. The bed of the channel is somewhat sandy and shifting, gravel bars forming at times along the bends of the river and again being displaced at the next high water. Measurements were made from the footbridge above mentioned. The station was valuable as furnishing information concerning the flow of the San Juan into New Mexico and the amount of water available for the use of the Indians along its border, as well as for use on tracts of the public domain.

The well-known Pagosa Mineral Springs are situated upon the headwaters of the San Juan, and a railroad has recently been constructed into this territory.[c]

[a] For detailed information concerning the agriculture of this region, see the State Engineers' Reports.

[b] For more detailed information concerning this drainage basin, see Hayden's Report of 1875. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 278; Nineteenth, Part IV, p. 409; Twentieth, Part IV, p. 400; Bulletin, No. 140, p. 195; Water-Supply and Irrigation Paper No. 38, p. 307. Also Tenth Biennial Report of the State Engineer of Colorado, p. 330. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, pp. 90–135.

[c] For more detailed data concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 498; Ninth, p. 388; Tenth, p. 331. Also publications U. S. Geological Survey: Eighteenth Annual Reports, Part IV, p. 279; Nineteenth, Part IV, p. 409; Twentieth, Part IV, p. 401; Twenty-first, Part IV, p, 297; Bulletin No. 140, p. 195; Water-Supply and Irrigation Papers No. 11, p. 71; No.16, p. 144; No. 28, pp. 138, 142, and 145; No. 38, p. 307; No. 39, p. 451. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 102.

A. GAGING STATION ON SAN JUAN RIVER AT ARBOLES.

B. GAGING STATION ON PIEDRA RIVER AT ARBOLES.

Discharge of San Juan River at Arboles.

[Altitude, 5,998 feet; drainage area, 1,394 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec. ft.*		
April	.....	1,123	1,987	1,498	[b] 934	1,383	82,294	0.99	1.10
May	.....	1,635	3,393	1,884	917	1,957	120,331	1.40	1.61
June	[b] 1,261	444	2,311	2,390	550	1,391	82,770	1.00	1.11
July	635	256	685	1,022	523	624	38,368	.45	.52
August	422	189	303	255	385	311	19,123	.22	.25
September	220	309	607	123	219	296	17,613	.21	.23
October	206	250	1,019	99	.....	394	24,226	.28	.32
November	197	210	396	83	.....	222	13,210	.16	.18
Mean	490	552	1,338	918	588	822	397,935	.59	5.32
Acre-feet for period recorded	177,785	267,180	647,576	444,324	213,561	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

[b] Approximate, only part of month.

Maximum and minimum discharge and average run-off of San Juan River at Arboles for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 11	135	June 19	1,770	0.39	0.35
1896	Aug. 22	136	May 6	2,615	.45	.40
1897	Aug. 31	182	May 20	4,423	1.07	.96
1898	Sept. 25	83	June 24	3,255	.73	.66
1899	Sept. 8	96	May 13	1,976	.47	.42

[a] The run-off given in the horizontal lines is the amount for that part of each year covered by the record and the depths in inches is for a period of thirty days at the rate given as the mean in second-feet per square mile for the period covered. The discharge given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

Discharge measurements made on San Juan River at Arboles.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 21	F. Cogswell	7.30	1,556
Aug. 30	do	6.20	387
Oct. 11	do	5.80	215
Nov. 25	do	5.90	252
1896.			
May 16	F. Cogswell	6.65	768
June 21	do	5.90	250
July 25	do	6.00	268
Sept. 26	do	6.15	322
Oct. 24	do	6.20	349
1897.			
Apr. 25	F. Cogswell	8.30	2,753
May 16	do	8.80	3,316
June 27	do	7.60	1,604
July 25	do	6.50	446
Aug. 29	do	5.80	209
Sept. 26	do	8.00	2,048
Oct. 24	do	6.90	795
1898.			
Apr. 12	A. L. Fellows	7.30	1,403
May 17	do	7.42	1,497
June 21	do	8.10	2,579
Aug. 8	G. H. Matthes	6.30	294
Aug. 21	A. L. Fellows	6.05	213
Oct. 23	do	5.80	83

Discharge measurements made on San Juan River at Arboles.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 23	A. L. Fellows	7.00	1,286
May 22	do	6.60	737
June 26	do	6.15	277
Nov. 26	do	5.75	127

PIEDRA RIVER AT ARBOLES.

This tributary of San Juan River rises among the San Juan Mountains in Hinsdale and Mineral counties, in southern Colorado, and flows in a nearly southerly direction to its junction with the San Juan about one-quarter of a mile west of the old Denver and Rio Grande Railroad station at Arboles. Very little irrigation is practiced upon this stream, and that little is along the lower course of the river. It is possible, however, to take water out for the irrigation of mesa lands lying along the west side of the stream between it and Los Pinos River. The value of the information derived from the maintenance of this station is due to the fact that it is an important source of supply for the Indians along its borders and for the owners of lands along the San Juan below their junction.[a]

[a] For more detailed information concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 504; Ninth, p. 390; Tenth, p. 334. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 281; Nineteenth, Part IV, p. 411; Twentieth, Part IV, p. 402; Twenty-first, Part IV, p. 298; Bulletin No. 140, p. 196; Water-Supply and Irrigation Papers No. 11, p. 71; No. 16, p. 145; No. 28, pp. 139, 142 and 145; No. 38, p. 308; No. 39, p. 452.

Discharge of Piedra River at Arboles.

[Altitude, 5,998 feet; drainage area, 670 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	.....	[b] 804	1,460	978	[c] 380	906	53,911	1.352	1.51
May	([d])	1,048	2,025	966	315	1,089	66,960	1.625	1.88
June	432	229	1,189	1,211	168	646	33,440	.964	1.07
July	346	111	296	585	141	296	18,200	.442	.51
August	200	59	106	149	180	139	8,547	.207	.24
September	115	347	399	89	49	200	11,901	.299	.33
October	125	175	840	70	.....	303	18,631	.452	.52
November	93	121	241	37	.....	123	7,319	.184	.20
Mean	219	362	820	511	206	463	223,909	.691	6.26
Acre-feet for period recorded	71,610	167,298	396,988	247,416	90,798	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

[b] April 12 to 30 inclusive.

[c] April 23 to 30 inclusive.

[d] May 19 to 30 inclusive.

Maximum and minimum discharge and average run-off of Piedra River at Arboles for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 6	60	July 12	6.70	0.37	0.327
1896	Aug. 11	23	May 6 Sept. 24	2,066 3,000	.60	.540
1897	Aug. 25	65	May 7	2,398	1.36	1.224
1898	Nov. 13	27	Apr. 27	1,599	.84	.763
1899	Sept. 6	25	May 13	643	.35	.307

[a] The run-off given is the amount for that part of each year covered by the records and the depth in inches for a period of thirty days as the rate given as the mean in second-feet per square mile for that period covered. The discharge given is for average months and the total for an average period of eight months as derived from the observations. Details may be found in the authorities cited.

Discharge measurements made on Piedra River at Arboles.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 21	A. P. Davis and F. Cogswell	3.90	606
Aug. 30	F. Cogswell	3.20	235
Oct. 11	do	2.90	140
Nov. 25	do	2.80	115
1896.			
May 18	F. Cogswell	3.90	544
June 20	do	2.90	109
July 24	do	3.05	189
Sept. 27	do	3.70	405
Oct. 25	do	3.00	179
1897.			
Apr. 24	F. Cogswell	5.20	1,429
May 15	do	5.65	1,629
June 26	do	4.20	677
July 24	do	3.10	230
Aug. 28	do	2.60	65
Sept. 25	do	4.15	675
Oct. 23	do	4.00	586
1898.			
Apr. 13	A. L. Fellows	4.80	1,158
May 16	do	4.52	937
June 22	do	5.10	1,315
Aug. 8	G. H. Matthes	3.10	195
Aug. 24	A. L. Fellows	3.05	186
Oct. 24	do	2.60	52

Discharge measurements made on Piedra River at Arboles—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 23	A. L. Fellows	3.80	499
May 22	do	3.40	279
June 26	do	2.90	111
Nov. 26	do	2.80	88

LOS PINOS RIVER AT IGNACIO.

This stream drains the country near the western end of the San Juan Range and the southern slope of the Needle Mountains. It flows in a southerly direction for about 50 miles, crossing the Colorado line about 5 miles south of La Boca, on the Denver and Rio Grande Railroad. The valley is in general wider than the valleys of the Piedra and San Juan, and irrigation is more extensively practiced along the borders of the stream. A number of canals have been constructed by the Government for the benefit of the Indians located on the bottom lands. Several irrigation canals have also been projected, and surveys have been made by private parties for the purpose of taking out water to the adjacent mesas. The station is important as giving information concerning the supply of water available for the use of the Indians and of white settlers as well. The Indians have in general taken lands in severalty in the first bottom lands of the stream, but since the reservation was thrown open many white settlers have filed on lands higher up. The normal supply of this stream will probably eventually prove insufficient for irrigation, and this may be true even with storage. There are, however, some very fine reservoir sites upon the headwaters of the stream which may be used.

The gaging station is located at the subagency, about 2 miles north of the station of the Denver and Rio Grande Railroad. The channel is fairly suitable at this point, being of gravel and bowlders, and has suffered little change since the station was established. Measurements are usually made at the wagon bridge, to which the rod is attached, but may at times of low water be made by wading. The channel is fairly stable at this point, the banks, although low, not being particularly liable to overflow. Records have been irregular and unsatisfactory, but a table is compiled from the few that have been sent in.[a]

[a] For more detailed data concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 336. Also publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 299; Water-Supply and Irrigation Papers, No. 38, p. 309; No. 39, p. 452; No. 50, p. 380.

Estimated monthly discharge of Los Pinos River at Ignacio.

[Altitude, 6,422 feet; drainage area, 450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
April 23 to 30	.....	.....	479	29,693	1.11	1.24
May	947	180	530	32,588	1.18	1.36
June	605	264	469	27,907	1.04	1.16
July	662	124	289	17,770	.64	.74
August	1,346	49	349	21,459	.77	.89
September	264	36	62	3,689	.14	.16
October	292	36	127	78,088	.28	.32
November	124	89	103	6,129	.23	.26
December 1 to 21	89	49	59	3,628	.13	.15
1900.						
January	101	61	82	5,042	.19	.22
February	61	61	61	3,388	.13	.13
March	141	61	94	5,780	.21	.24
April 1 to 7	193	101	166	9,878	.36	.40
May 9 to 26	1,326	785	998	61,365	2.22	2.56

Discharge measurements made on Los Pinos River at Ignacio.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Apr. 22	3.20	437
May 20	3.40	577
June 25	2.80	244
Nov. 25	2.60	124
1900.		
Mar. 26	2.60	137
May 8	3.50	604
Aug. 14	2.00	25

FLORIDA RIVER AT STEWART'S RANCH, NEAR DURANGO.

This stream is a tributary of Animas River, and drains the country immediately west of that drained by the Los Pinos. Irrigation is extensively practiced along this stream, particularly along its lower course, and the supply, being insufficient, is exhausted early in the irrigation season. Owing to the fact that there are large tracts of land

along the stream that might be cultivated if there were enough water, a project has been considered for storing water in the upper portion of the drainage basin. The land is particularly valuable, being located near the city of Durango and being at such an altitude that wheat and other grains may be most successfully raised. The station was maintained for a portion only of one summer, with a view to ascertaining the high-water discharge. The data thus derived are given in full.[a]

Estimated monthly discharge of Florida River at Durango.

[Drainage area, 136 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
May 21 to 31			139	8,547	1.02	1.18
June	121	12	68	4,046	.50	.56
July	211	6	45	2,767	.33	.38

The only gagings made in the year 1899 are as given below:

Discharge measurements made on Florida River at Durango.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
May 19	2.25	236
June 24	.70	9

ANIMAS RIVER AT DURANGO.

This stream is the largest tributary of the San Juan, and derives its water from the high mountains above Silverton, draining portions of the Needle and La Plata mountains, in addition to the area south of Mount Sneffels and Red Mountain. The country drained by this stream and its tributaries is generally very mountainous down to a point about 12 miles above the city of Durango, where the valley broadens out to such an extent that irrigation is extensively practiced. The supply of water is probably more than adequate to meet all demands for irrigation, although a number of projects are being con-

[a] For more detailed data concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 340. Also publications U. S. Geological Survey: Twenty-first Annual Report, Part IV, p. 300; Water-Supply and Irrigation Papers, No. 38, p. 311; and No. 39, p. 452. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

sidered with a view to using the waters of this river and of its tributaries for the development of power, both directly and through the transmission of electricity. An important project has also been undertaken for the construction of a large canal using the water of the Animas River in New Mexico.

The station is located at the wagon bridge, a short distance west of the railroad station at Durango. In 1889 a new bridge was constructed, rendering the new station much more satisfactory than the old one had been. The stream is usually gaged from the wagon bridge, but may at very low water be gaged by wading. The channel is of bowlders, and is fairly stable, although occasional changes occur. The banks are high and not liable to overflow.[a]

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[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 510; Ninth, p. 392; Tenth, p. 342. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 283; Nineteenth, Part IV, p. 414; Twentieth, Part IV, p. 403; Twenty-first, Part IV, p. 301; Bulletin No. 140, p. 198; Water-Supply and Irrigation Papers, No. 11, p. 72; No. 16, p. 146; No. 28, pp. 139, 142, and 145; No. 38, p. 310; No. 39, p. 452; No. 50, p. 383. Also, Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 116.

Estimated mean discharge of Animas River at Durango.

[Altitude, 6,551 feet; drainage area, 812 square miles.]

Month	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
January	.....	.....	[b]310	[b]378	.....	[b]179	389	23,919	0.48	0.55
February	.....	.....	[b]284	[b]267	.....	[b]133	261	14,495	.32	.33
March	.....	.....	[b]374	[b]306	.....	[b]224	301	18,508	.37	.43
April	.....	[c]1,634	2,608	1,510	584	335	1,334	79,379	1.64	1.83
May	.....	2,326	4,498	1,765	1,730	2,183	2,500	153,719	3.08	3.55
June	[d]646	875	3,218	3,431	1,797	1,990	1,993	118,592	2.45	2.73
July	388	349	1,120	1,364	668	409	716	44,025	.88	1.01
August	510	199	534	364	691	179	413	25,394	.51	.59
September	363	1,004	875	263	276	231	502	29,871	.62	.69
October	307	475	1,385	161	297	252	480	29,514	.59	.68
November	246	274	553	158	267	205	289	17,197	.36	.40
December	[b]251	[b]216	430	[b]250	[b]212	[b]272	272	16,725	.34	.39
Mean	387	816	1,349	851	724	550	788	571,338	.97	13.18
Acre-feet for period recorded	149,760	426,908	979,347	615,997	388,900	398,215	.....	.....	.....	.....

[a] The run-off given in the above table is for normal months and the totals for a normal year as derived from the observations. Details may be found in the authorities cited.

[b] Approximate.

[c] April 12 to 30, inclusive.

[d] June 20 to 30, inclusive.

Maximum and minimum discharge and average run-off of Animas River at Durango for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Aug. 12, Dec. 15	208	Aug. 14	990	3.82	0.48
1896	Aug. 26	138	Sept. 24	[b] 7,800	10.18	1.00
1897	Aug. 27	325	May 25	5,870	22.61	1.66
1898	Nov. 19	125	June 23	4,677	14.25	1.05
1899	Apr. 6	138	May 14	3,240	9.09	.89
1900	Feb. 17	122	May 28	3,830	9.58	.69

[a] The run-off given is the amount for that part of each year covered by the records and the depth in inches for the time. Details may be found in the authorities cited.
[b] Approximate.

Discharge measurements made on Animas River at Durango.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 18	F. Cogswell	6.50	1,893
Aug. 29	do	5.80	543
Oct. 10	do	5.40	328
Nov. 24	do	5.20	260
1896.			
May 15	F. Cogswell	6.35	1,063
June 19	do	5.80	590
July 23	do	5.50	360
Sept. 25	do	7.40	2,566
Oct. 23	do	5.50	414
1897.			
Apr. 23	F. Cogswell	7.75	2,176
May 14	do	9.20	4,786
June 25	do	7.85	2,534
July 23	do	6.10	997
Aug. 27	do	5.10	328
Sept. 24	do	6.05	905
Oct. 22	do	6.50	1,121
1898.			
Apr. 11	A. L. Fellows	6.50	1,356
May 15	do	7.25	1,797
June 20	do	8.55	3,475
Aug. 5	G. H. Matthes	5.20	414
Aug. 22	A. L. Fellows	5.07	284
Oct. 22	do	4.70	160

Discharge measurements made on Animas River at Durango—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 21	A. L. Fellows	7.50	698
May 19	do	9.45	2,635
June 24	do	8.10	1,256
Sept. 28	do	6.52	223
Nov. 25	do	6.50	201
1900.			
Mar. 26	A. L. Fellows	6.60	246
May 9	do	8.65	1,614
June 25	do	8.80	1,740
Aug. 13	do	6.45	169

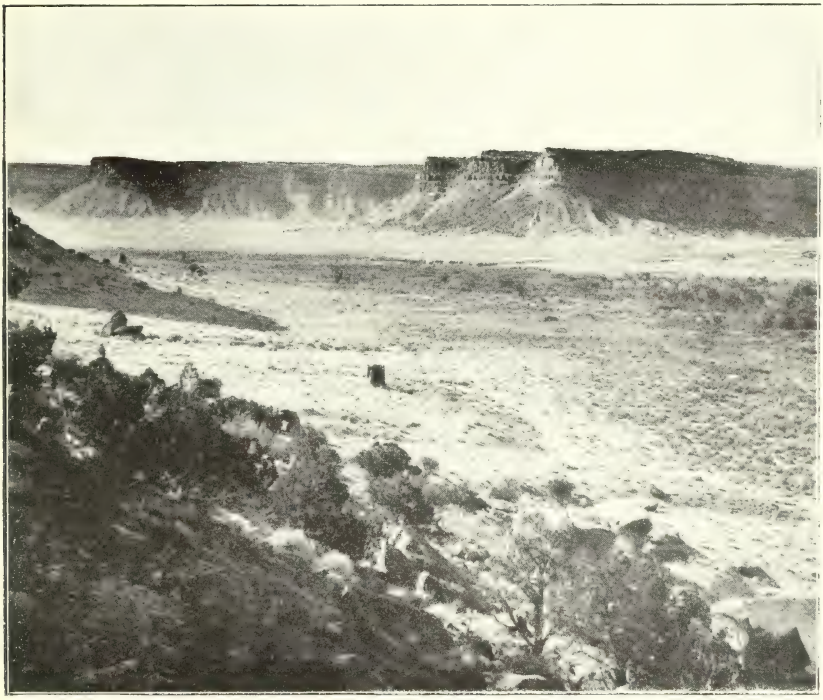
MANCOS RIVER AT MANCOS.

Mancos River rises on the southwestern slopes of the La Plata Mountains and flows in a generally southwesterly direction, emptying into the San Juan at a point about 6 miles east of the southwest corner of the State of Colorado, or the Four Corners. The upper portion of the drainage is mountainous, and little irrigation is possible until the valley broadens out in the vicinity of the town of Mancos, where all of the ordinary flow of the stream is used. Enough water goes to waste, however, at high stages to irrigate probably all of the available land along the stream if it could be properly stored. For the last 40 miles of its course the stream flows through the Mesa Verde in what is known as the Mancos Canyon, this lying in the Southern Ute Indian Reservation.[a] With plenty of water, considerable land might be irrigated for the benefit of the Indians in this canyon, but under existing conditions the stream is dry during a greater part of the summer season, and hence no irrigation is possible.

The station is located at the town of Mancos, a short distance below a wagon bridge near the center of the town. A number of ditches take their supply of water at points above the station and a number of others are located below. The channel is not gravel and is somewhat shifting, the bed changing so much in the year 1900 that no rating table was possible for that year.[b]

[a] Hayden's Report of 1875.

[b] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Ninth, p. 394; Tenth, p. 346. Publications U. S. Geological Survey: Twentieth Annual Report, Part IV, p. 404; Twenty-first, Part IV, p. 284; Water-Supply and Irrigation Papers, No. 28, pp. 137, 142, 144; No. 38, p. 312; No. 39, p. 452, and No. 50, p. 384. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.



A. MANCOS CANYON IN MESA VERDE.

B. GRAND RIVER AT GRAND JUNCTION.

Estimated monthly discharge of Mancos River at Mancos.

[Altitude, 6,960 feet; drainage area, 117 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
March[a]			50	3,074	0.43	0.49
Apr. 10 to 30	375	123	261	15,531	2.23	2.49
May	270	144	206	12,667	1.76	2.03
June	291	144	213	12,674	1.82	2.03
July	333	2	104	6,395	.89	1.02
August	12	8	9	553	.08	.09
September	12	3	7	399	.06	.07
October[a]			5	307	.04	.04
November[a]			3	179	.03	.03
				51,779	.82	8.29
1899.						
March[a]			90	5,534	0.77	0.89
April	91	5	42	2,499	.36	.40
May	144	19	74	4,550	.63	.72
June	81	5	33	1,964	.28	.31
July	19	3	9	533	.08	.09
August	102	8	41	2,521	.35	.40
September	123	5	33	1,964	.28	.31
October	60	1	22	1,353	.19	.22
November[a]			5	298	.04	.04
				19,268	.30	3.07

[a] Approximate, no observations being made during these periods.

Discharge measurements made on Mancos River at Mancos.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1898.	*Feet.*	*Sec.-ft.*
Apr. 9	1.80	102
May 14	2.20	185
June 18	2.00	159
Oct. 18	.80	3

Discharge measurements made on Mancos River at Mancos.—Continued.

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Apr. 19	1.65	70
May 18	1.60	56
June 23	1.10	9
Sept. 22	.90	2
Nov. 24	1.00	3
1900.		
Mar. 23	1.05	4
May 7	1.80	82
June 26	1.70	16
Aug. 12	1.40	2

MISCELLANEOUS INVESTIGATIONS.

A number of miscellaneous gagings have been made at different points in this division, and are given in the table below. Most of these were taken during an investigation looking to the irrigation of lands belonging to the Southern Ute Indians. A full description of this investigation, with a statement of its results, may be found in the Twentieth Annual Report, Part IV, pages 408–434, and in the Twenty-first Annual Report, Part IV, page 286 et seq.

No seepage measurements have been made upon any of the streams of this region, but it is likely that the return from seepage is slight, as the stratification is such as to make any great returns improbable.

This region is also discussed in Hayden's Report for 1875.

Miscellaneous discharge measurements of San Juan River and tributaries.

[Hydrographer, Gerard H. Matthes.]

Date.	Stream.	Locality.	Discharge.
1898.			*Sec.-ft.*
Aug. 6	Los Pinos River	6 miles above Ignacio	246
Aug. 7	do	4 miles below Ignacio	196
Aug. 10	La Plata River	Hesperus	11
Aug. 18	San Juan River	Noland, Utah	609
Sept. 21	do	do	383
1899.			
Sept. 13	Mancos River	Head of canyon	3
Oct. 14[a]	do	In Mancos Canyon	100+

[a] Estimated discharge for several hours following a heavy rain.

GRAND RIVER DIVISION.

IRRIGATION.

Grand River is the largest stream in Colorado, and drains the greatest territory. The main stream rises in Middle Park, in north-central Colorado, and drains the mountainous country on the west side of the Front Range and the south side of the Continental Divide in Middle Park. The Grand River and all of its tributaries flow through mountainous regions for considerable portions of their courses, and then generally enter a country the surface of which is usually undulating, but at times badly broken by deep canyons and ravines, the bottoms of these canyons being sometimes valleys of considerable extent, and again narrowing to mere threads. Along these canyons and valleys are often mesas of varied breadths. Upon most of the streams of this division but little irrigation has been practiced, except along the lowest valleys. There are, however, a few exceptions to this rule, the most notable ones being the Uncompahgre and Dolores rivers, which will be described more fully later. Upon some of the streams as, for example, the San Miguel—a great deal of water is used for the purpose of developing power, the supply upon this stream being hardly adequate to the demands. Considerable power is developed upon other streams of this region also, the San Miguel, the Lake Fork of the Gunnison, and the Dolores being examples. Owing to the comparatively small amount of land that can be irrigated along the main stream, only a small proportion of the water in this division has been used, but a number of projects are under consideration with a view to diverting the water in great canals to the fertile mesas along the various streams, and in one case—namely, the Gunnison River—of taking water from that stream through the Divide for the purpose of irrigating lands in another valley—the Uncompahgre. Another great project now under consideration is that of taking the water of Grand River, by means of a very large canal, to the uplands of the western part of Colorado and the eastern part of Utah.

A number of the smaller tributaries of the Grand and its branches furnish a supply that is inadequate for the demands of irrigation, and storage is resorted to on a number of these streams, Surface Creek and Roan Creek being examples. The crops of this region vary with the altitude, only hay and grain being raised at the higher elevations, while fruits of an almost tropical nature may be raised where the Grand crosses the State line into Utah. A beet-sugar factory has been located at Grand Junction, and is successfully operated.

Irrigation division No. V, the Grand River division, covers the lands irrigated by the Grand and its tributaries. The relations existing between the different districts of this division are not so close as

is usually the case in the eastern half of the State. Except in a few cases the different districts are not interdependent, so that the water in one district is generally used without much reference to others, this being usually due to the fact that each stream flows into a river so large (the Grand) that its supply has not yet been exhausted. This will not long remain the case, however, and eventually the interdependence of the different districts will undoubtedly be almost as close as it is upon the South Platte.

There are 20 districts in this division, for the names and boundaries of which see Biennial Reports of the State Engineers of Colorado. For map see Pl. I of this paper, p. 20.

STREAM MEASUREMENTS.

The following stations have been maintained for a length of time sufficient to warrant publication of the records, measurements at other stations being given in the list of miscellaneous measurements for this division. These stations are at Glenwood Springs and Grand Junction, on Grand River; Iola and Grand Junction, on Gunnison River; Fort Crawford and Montrose, on Uncompahgre River; Dolores, on Dolores River; and Fall Creek, on San Miguel River.[a]

GRAND RIVER AT GLENWOOD SPRINGS.

This station was located May 12, 1899, at the request of the Denver and Rio Grande Railroad Company, at the railroad bridge one-quarter of a mile west of the depot and just above the mouth of Roaring Fork. A wire gage was used at this point, but records were kept up during the stage of high water only. On January 1, 1900, a new gage rod was located near the Glenwood Springs electric-light plant. Measurements are made from the wagon bridge across the river near the railroad station. The channel is good, being composed of gravel and of rock, and is not liable to great change, and the banks are high and not subject to overflow. Gagings are made from the bridge. The station is of importance, as it furnishes a good idea of the flow of Grand River available for the great irrigation projects contemplated below, measurements being made of Roaring Fork also whenever they are made at the Glenwood station.[b]

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[a] For further descriptions of this division see Hayden's Report of 1875. Also publications U. S. Geological Survey: Twelfth Annual Report, Part II, p. 290; Eighteenth, Part IV, p. 260; Nineteenth, Part IV, p. 360; Twentieth, Part IV, p. 373; Twenty-first, Part IV, p. 280; Bulletins No. 13, p. 47; No. 140, p. 186, and Water-Supply and Irrigation Papers. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell. For agricultural statistics see Biennial Reports of the State Engineers of Colorado.

[b] For more specific information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 350; Water-Supply and Irrigation Papers, U. S. Geological Survey, No. 37, p. 293; No. 50, p. 375, and Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 112.

Estimated monthly discharge of Grand River at Glenwood Springs.

[Altitude, 5,743 feet; drainage area, 5,838 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
January	970	810	890	54,724	0.15	0.17
February	935	810	883	49,039	.15	.16
March	1,460	902	1,187	72,896	.20	.23
April	3,940	1,120	1,818	108,178	.31	.35
May	22,895	3,245	11,963	735,577	2.05	2.36
June	22,390	7,622	14,817	881,673	2.54	2.83
July	7,270	1,515	3,121	191,903	.54	.62
August	1,460	935	1,134	69,727	.19	.22
September	870	755	800	47,603	.14	.16
October	755	755	755	46,423	.13	.15
November	935	728	805	47,901	.14	.16
December	840	570	681	41,873	.12	.14
The year	22,895	570	3,238	2,347,607	.56	7.55

Discharge measurements made on Grand River at Glenwood Springs.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
May 12	6.05	17,577
June 17	10.22	29,187
November 17	2.75	1,084
1900.		
March 19	3.80	1,140
July 8	5.40	3,764
August 23	3.60	1,086

GRAND RIVER AT GRAND JUNCTION.

This station was established October 18, 1894, and is located at the State wagon bridge across Grand River near the pump house of the city waterworks at Grand Junction, a short distance above the mouth of Gunnison River. The Grand at this point discharges through two channels, and a separate record of each is maintained, requiring separate discharge measurements. During the last four years by far the greater part of the water has run through the left channel; during the year 1900 there was a flow through the right channel for but a short time. Gage rod No. 1 is attached to the pier on the right bank of the river on the lower side; gage rod No. 2 consists of a wire and weight

fastened to the upper side of the bridge over the left channel. The channel is sandy and shifting, and the discharge must therefore be considered as approximate only. Owing to the small number of measurements made and to the changes in the channel it has been found impracticable to construct rating tables covering the entire period, so that the discharge for 1895, 1896, and 1900 are not given.[a]

Estimated total monthly discharge of Grand River at Grand Junction.

[Altitude, 4,594 feet; drainage area, 8,644 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
January			[b]1,000	[b]61,488	[b]0.12	[b]0.14
February			[b]1,050	[b]58,314	[b].12	[b].12
March			[b]1,100	[b]67,637	[b].13	[b].15
April	11,476	1,280	3,723	221,534	.43	.48
May	37,950	12,785	29,436	1,809,948	3.41	3.93
June	37,008	15,618	25,350	1,508,429	2.93	3.27
July	15,006	3,400	8,830	542,935	1.02	1.18
August	5,470	1,720	3,000	184,463	.35	.40
September	2,650	1,640	1,803	107,286	.21	.23
October	2,350	1,560	1,813	111,478	.21	.24
November	1,820	1,455	1,663	98,955	.19	.21
December			[b]1,550	[b]95,306	[b].18	[b].21
The year	37,950		6,693	4,867,773	.78	10.56
1898.						
January			[b]2,944	[b]181,020	[b].34	[b].39
February			[b]2,985	[b]165,777	[b].35	[b].36
March			[b]2,113	[b]129,924	[b].24	[b].28
April			[b]4,305	[b]256,165	[b].50	[b].56
May	12,642	4,633	7,130	438,406	.83	.94
June	17,262	8,279	13,702	815,326	1.59	1.77
July	7,611	1,725	4,445	273,312	.51	.59
August	1,725	949	1,127	69,297	.13	.15
September	1,143	561	907	53,970	.11	.12
October	1,143	561	915	56,261	.11	.13
November	1,337	755	1,072	63,788	.12	.14
December			1,011	62,164	.17	.20
The year	17,262		3,555	2,565,410	.42	5.63

[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 534; Ninth, p. 396; Tenth, p. 352. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 260; Nineteenth, Part IV, p. 400; Twentieth, Part IV, p. 389; Twenty-first, Part IV, p. 281; Bulletins, No. 131, p. 48; No. 140, p. 187; Water-Supply and Irrigation Papers No. 11, p. 67; No. 16, p. 137; No. 28, pp. 135, 142, and 144; No. 37, p. 294; No. 39, p. 451; No. 50, p. 376. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 121.

[b] Approximate.

Estimated total monthly discharge of Grand River at Grand Junction—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1899.						
March			1,799	110,616	0.21	0.24
April			3,940	234,446	.46	.52
May			19,375	1,191,322	2.24	2.59
June			31,306	1,862,836	3.62	3.99
July			14,070	865,130	1.63	1.88
August			4,577	281,429	.53	.21
September			2,164	128,886	.25	.68

Discharge measurements made on Grand River at Grand Junction.

[Total discharge of both channels.]

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Oct. 18	A. P. Davis	2.10	1,585
1895.			
June 27	A. P. Davis	4.03	16,500
Oct. 1	do	.82	2,059
1896.			
Aug. 20	F. Cogswell	3.00	1,023
Sept. 20	do	3.90	1,694
Oct. 17	do	3.60	1,542
Nov. 10	C. C. Babb	3.35	1,497
1897.			
Apr. 20	C. C. Babb	5.60	5,176
May 19	W. B. Dougall	10.20	32,686
July 29	F. Cogswell	5.35	4,044
Sept. 29	do	4.05	2,062
Oct. 28	do	3.98	1,764
Nov. 23	C. C. Babb	3.90	1,423
1898.			
Apr. 25	A. L. Fellows	5.15	4,802
May 23	do	5.85	6,087
June 27	do	7.40	11,215
Aug. 27	do	3.35	1,237
Oct. 15	do	3.20	949

Discharge measurements made on Grand River at Grand Junction—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 15	A. L. Fellows	4.70	2,946
May 13	do	10.00	23,153
June 18	do	11.55	[a] 40,000
Sept. 19	do	4.20	1,989
Nov. 18	do	3.90	1,916
1900.			
Mar. 20	A. L. Fellows	4.15	1,762
July 7	do	5.80	6,177

[a] Approximate.

GUNNISON RIVER AT IOLA.

Gunnison River, the largest tributary of the Grand in Colorado, rises in the south central part of the State, in the Saguache Mountains and Cochetopa Hills, and flows in a westerly direction, emptying into the Grand near the western boundary of the State, a short distance from Grand Junction. Comparatively little of the water is yet used for irrigation, but a canal line has now been surveyed with a view to taking the water from Gunnison River and carrying it to the valley of the Uncompahgre for the purpose of irrigating the fertile plains there. It was for the purpose of determining the amount of water available for such a project that the Iola station was located, although several important tributaries enter the Gunnison between the point selected at Iola and the point where the canal would probably be taken out. The rod is placed at a wagon bridge which crosses the Gunnison about one-quarter of a mile above the railroad station of the Denver and Rio Grande Railroad at Iola, measurements having been made and records kept up during the year 1900 only. The channel is favorable to accuracy, being wide, and the bed being of gravel and bowlders and not particularly liable to change. The banks, although not high, are not subject to overflow.[a]

[a] For more specific information concerning this station see Tenth Biennial Report of the State Engineer of Colorado, p. 357; Water-Supply and Irrigation Paper, U. S. Geological Survey, No. 50, p. 378.

Estimated monthly discharge of Gunnison River at Iola.

[Drainage area, 2,298 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
April	1,258	551	773	45,997	0.34	0.38
May	4,388	1,157	2,875	176,777	1.25	1.44
June	4,265	1,460	2,726	162,208	1.19	1.33
July	1,359	350	727	44,701	.32	.37
August	450	350	360	22,136	.16	.18
September	350	250	260	15,471	.11	.12
October	250	250	250	15,372	.11	.13

Discharge measurements made on Gunnison River at Iola.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1900.	*Feet.*	*Sec.-ft.*
May 3	3.00	1,272
June 28	3.40	1,658
July 5	2.90	1,169
August 9	2.20	431
August 25	2.10	392

GUNNISON RIVER AT GRAND JUNCTION.

This station was located on July 3, 1895, at the wagon bridge across the Gunnison, about 1 mile from its junction with the Grand, and observations were made until December 21 of that year, after which none were made until 1897. The station was never satisfactory, high water from Grand River setting back into the mouth of the Gunnison, making the gage readings unreliable. The readings were discontinued, therefore, after the fall of 1899. The channel was uneven and somewhat shifting, some very large bowlders interfering very materially with the gagings. The banks are so high that there was no liability of overflow.[a]

[a] For more detailed information concerning this station see Biennial Reports of the State Engineers of Colorado: Eighth, p. 544; Ninth, p. 401; Tenth, p. 359. Also publications U. S. Geological Survey: Nineteenth Annual Report, Part IV, p. 404; Twentieth, Part IV, p. 390; Twenty-first, Part IV, p. 278; Bulletin No. 140, p. 189; Water-Supply and Irrigation Papers: No. 16, p. 141; No. 28, pp. 136, 142, and 144; No. 37, p. 297; No. 39, p. 451.

Estimated monthly discharge of Gunnison River at Grand Junction

[Altitude, 4,594 feet; drainage area, 7,935 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1897.						
May	20,732	11,844	16,921	1,040,438	2.13	2.46
June	19,116	5,370	11,161	664,124	1.41	1.57
July	5,370	1,510	3,231	198,668	.41	.47
August	1,850	160	975	59,951	.12	.14
September	1,510	160	628	37,369	.09	.09
October	2,020	1,060	1,472	90,510	.19	.22
November	1,200	230	933	55,517	.12	.13
1898.						
May	8,996	3,965	5,318	326,993	.67	.77
June	11,361	4,158	8,850	526,610	1.12	1.25
July	3,965	1,076	2,543	156,364	.32	.37
August	968	578	689	42,365	.09	.10
September	578	399	479	28,502	.06	.07
October	672	399	533	32,773	.07	.08
November	672	314	497	29,573	.06	.07
1899.						
April	8,792	968	3,550	211,240	.45	.50
May	16,750	3,902	10,296	633,080	1.30	1.50
June	16,752	8,078	12,380	736,662	1.56	1.74
July	8,430	2,246	4,349	267,410	.55	.63
August	4,562	908	1,921	118,118	.24	.28
September	1,000	758	875	52,066	.11	.12

Discharge measurements made on Gunnison River at Grand Junction.

Date.	Hydrographer.	Gage height.	Discharge.
1894.		*Feet.*	*Sec.-ft.*
Oct. 17	A. P. Davis	1.25	748
1895.			
June 28	A. P. Davis	4.74	4,178
July 17	do	3.60	2,642
Oct. 1	do	1.95	781
1897.			
Apr. 20	C. C. Babb	5.20	5,975
May 20	W. B. Dougall	7.30	6,644
July 28	F. Cogswell	2.65	1,814
Sept. 28	do	2.40	1,246
Oct. 27	do	2.50	1,270
Nov. 23	C. C. Babb	2.30	828

Discharge measurements made on Gunnison River at Grand Junction.—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Apr. 26	A. L. Fellows	4.65	5,932
May 23	do	4.50	4,647
June 28	do	4.62	5,274
Aug. 27	do	1.80	866
Oct. 15	do	1.50	578
1899.			
Apr. 15	A. L. Fellows	3.50	3,002
May 13	do	7.00	14,280
June 18	do	7.15	12,769
Sept. 19	do	2.20	1,061
Nov. 18	do	2.00	968
1900.			
Mar. 20	A. L. Fellows	2.50	1,477
July 7	do	2.90	2,121

UNCOMPAHGRE RIVER AT FORT CRAWFORD.

Uncompahgre River rises in Ouray County, in the high peaks of southwestern Colorado, and flows northwesterly, emptying into Gunnison River at Delta. The upper portion of its drainage basin is mountainous, but farther downstream the country is less broken and irrigation is possible along the valleys and adjacent mesas. Water is used to a certain extent for power purposes and in milling along the upper course of the stream. In the vicinity of Montrose a number of canals divert nearly all of the normal flow for irrigation purposes, and recourse must be had to storage or to the diversion of the waters of the Gunnison, already mentioned, for further irrigation in this district. The Fort Crawford station is located at a wagon bridge about one-quarter of a mile east of the railroad station at Fort Crawford, the post-office, known as Uncompahgre, being about 8 miles above, or south of, Montrose. The channel proved unsatisfactory, consisting of gravel bars which changed radically from time to time, rendering the rating tables untrustworthy. The discharge tables are therefore largely approximate.[a]

[a] For further details concerning this station, see Biennial Reports of the State Engineers of Colorado: Fifth, Part I, pp. 19 and 41, and Part II, Pl. XIX; Eighth, p. 528; Ninth, p. 403; Tenth, p. 361. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 265; Nineteenth, Part IV, p. 402; Twentieth, Part IV, p. 391; Twenty-first, Part IV, p. 279; Bulletin No. 140, p. 188; Water-Supply and Irrigation Papers, No. 11, p. 69; No. 16, p. 139; No. 28, pp. 136, 142, and 144; No. 37, p. 296; No. 39, p. 451. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.

Discharge of Uncompahgre River at Fort Crawford.

[Altitude, 6,168 feet; drainage area, 497 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.[a]	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		
April	.....	.....	386	327	263	325	19,339	0.65	0.72
May	.....	1,010	787	306	534	659	40,520	1.33	1.53
June	[b] 1,082	519	994	704	709	802	47,722	1.61	1.80
July	470	126	527	430	252	361	22,197	.73	.84
August	277	38	136	111	138	140	8,608	.28	.32
September	117	148	146	67	41	104	6,188	.21	.23
October	70	106	204	58	.....	109	6,702	.22	.25
November	82	86	127	54	.....	87	5,177	.18	.20
Mean	350	290	413	257	323	326	156,453	.66	5.89
Acre-feet for period recorded	110,346	123,050	194,424	124,440	117,303	.....	.....	.....	.....

[a] The run-off given is for average months and the total for an average eight months from April to November, inclusive, as calculated from the observations. Details may be found in the authorities cited.

[b] June 25 to 30.

Maximum and minimum discharge and average run-off of Uncompahgre River at Fort Crawford for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 6	55	June 28	1,535	0.78	0.70
1896	Aug. 15	10	May 27	3,375	.64	.58
1897	Sept. 1	55	June 15	1,467	.92	.83
1898	Aug. 3	15	June 24	985	.58	.52
1899	Sept. 10	4	June 15	1,163	.72	.65

[a] The run-off given is for that part of each year covered by the observations and for a thirty-day month, at the rate given as the mean second-feet per square mile for the period covered.

Discharge measurements made on Uncompahgre River at Fort Crawford.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 25	F. Cogswell	4.60	834
Aug. 26	do	3.25	218
Oct. 7	do	2.60	89
Nov. 18	do	2.55	92
1896.			
May 11	F. Cogswell	4.30	568
June 15	do	4.10	560
July 18	do	3.50	204
Aug. 21	do	2.90	31
Sept. 21	do	3.25	122
Oct. 18	do	3.10	95
1897.			
Apr. 18	F. Cogswell	3.90	487
May 10	do	4.55	884
June 21	do	5.05	1,081
July 19	do	4.50	473
Aug. 23	do	3.45	70
Sept. 20	do	3.85	153
Oct. 18	do	4.00	195
1898.			
Apr. 5	A. L. Fellows	3.55	91
May 9	do	3.92	203
June 15	do	5.18	720
Aug. 12	do	3.80	74

Discharge measurements made on Uncompahgre River at Fort Crawford—Cont'd.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Oct. 16	A. L. Fellows	3.75	56
1899.			
Apr. 16	A. L. Fellows	4.50	328
May 15	do	5.22	747
June 19	do	5.18	773
Sept. 21	do	3.65	69
Nov. 20	do	3.70	79

UNCOMPAHGRE RIVER AT MONTROSE.

This station was located at Montrose in the fall of 1899, no records being kept, however, until the spring of 1900. There is but little water at this point during the greater part of the year, as the canals above divert most of the flow. The station is located at a bridge crossing the river opposite the town of Montrose, about one-half of a mile from the station of the Denver and Rio Grande Railroad. The channel is favorable to accuracy, being of gravel and bowlders and not liable to change, and the banks are high and not subject to overflow. Records were kept up for a short time only, as there was but little water during the greater part of the irrigation season of 1900.[a]

Estimated monthly discharge of Uncompahgre River at Montrose.

[Altitude, 5,811 feet; drainage area, 565 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
April 8–30	71	18	50			
May	369	51	177	10,883	0.31	0.36
June	369	122	260	15,471	.46	.52
July 1–7	158	68	127			

[a] For further details concerning this station, see Tenth Biennial Report of the State Engineer of Colorado, p. 363. Also Water-Supply and Irrigation Paper, U. S. Geological Survey, No. 50, p. 379.

Discharge measurements made on Uncompahgre River at Montrose.

[Hydrographer, A. L. Fellows.]

Date.	Gage height.	Discharge.
1899.	*Feet.*	*Sec.-ft.*
Sept. 20	0.40	15
Nov. 20	.45	15
1900.		
July 5	1.80	150
Aug. 10	.50	2

DOLORES RIVER AT DOLORES.

Dolores River is an important tributary of Grand River, rising in the La Plata and San Miguel Mountains, of which the highest peak, Mount Wilson, attains an elevation of over 14,000 feet. Its course is southwesterly for about 50 miles, where it turns and flows in an almost due northerly direction for nearly 100 miles, when it again turns west and enters Grand River, after crossing the Colorado-Utah line. The river flows for the greater part of its course through deep canyons, and comparatively little irrigation is practiced along the stream itself, excepting in the vicinity of Dolores, where for some 40 miles the valley widens out to from one-half of a mile to one mile, and a considerable area is cultivated. In the Paradox Valley again considerable land is cultivated, mostly, however, from small tributaries running into the main stream. At Rico a portion of the water is used for the development of power. By far the greater part of Dolores River, however, is used in the San Juan irrigation division, being diverted by means of a tunnel and a great cut into the Montezuma Valley. The head gates of the canals carrying this water are about 2 miles west of the present town of Dolores. The gaging station is located above these head gates and about one-half of a mile above the Rio Grande Southern Railroad station at Dolores. The channel is fairly favorable to accurate results, the bed being of small stones and gravel, and the banks being high and not liable to overflow.[a]

[a] For further details concerning this station, see Biennial Reports of the State Engineers of Colorado: Eighth, p. 516; Ninth, p. 405; Tenth, p. 364. Also publications U. S. Geological Survey: Eighteenth Annual Report, Part IV, p. 261; Nineteenth, Part IV, p. 407; Twentieth, Part IV, pp. 312 and 408; Twenty-first, Part IV, p. 282; Bulletin No. 140, p. 191; Water-Supply and Irrigation Papers: No. 11, p. 68; No. 16, p. 143; No. 28, pp. 138, 142, and 144; No. 38, p. 305; No. 39, p. 451; No. 50, p. 380. Also Report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 122.

Discharge of Dolores River at Dolores.

[Altitude, 6,942 feet; drainage area, 524 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	1900.	Mean.	Equivalent in acre-feet.	Mean run-off.[a] Second-feet per square mile.	Mean run-off.[a] Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b]500	747	1,483	1,092	437	284	757	45,045	1.44	1.61
May	[b]800	952	2,436	1,207	785	1,318	1,250	76,859	2.39	2.76
June	[b]800	263	1,465	1,510	499	808	891	53,018	1.70	1.90
July	270	130	268	490	207	84	258	15,864	.49	.56
August	248	38	148	120	204	29	131	8,055	.25	.29
September	99	195	394	78	33	90	148	8,807	.28	.31
October	79	113	391	37	93	83	132	8,116	.25	.29
November	134	179	172	48	49	88	111	6,605	.21	.23
Mean	366	327	855	573	288	348	460	222,369	.88	7.95
Acre-feet for period recorded	177,144	158,356	413,824	277,428	139,324	168,360	.....	.....	.....	.....

[a] The run-off given in the horizontal lines is the total acre-feet for the eight months of each year. That given in the vertical columns is the acre-feet for normal months and the total for a normal eight months, the average monthly flow from each square mile, and the average for the eight months and the normal depth in inches for each normal month with the total depth for the normal eight months. Details may be found in the authorities cited.

[b] Estimated.

Maximum and minimum discharge and average run-off of Dolores River at Dolores for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Nov. 8	42	June 27	848	0.78	0.70
1896	Aug. 16	8	Apr. 26	1,578	.69	.62
1897	Aug. 31	76	Apr. 18	2,944	1.82	1.63
1898	Sept. 25	34	June 2	2,030	1.22	1.09
1899	Sept. 5	23	May 14	1,461	.61	.55
1900	Aug. 26	20	May 19	1,731	.73	.66

[a] The run-off given is the total acre-feet for the eight months of each year, the average second-feet per square mile, and the depth in inches for thirty days at the average rate.

Discharge measurements made on Dolores River at Dolores.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 22	F. Cogswell	3.50	756
Aug. 28	do	2.70	163
Oct. 9	do	2.50	89
Nov. 20	do	2.40	75
1896.			
May 13	F. Cogswell	3.50	553
May 14	do	3.50	586
June 17	do	3.00	179
July 21	do	2.80	124
Aug. 24	do	2.60	42
Sept. 23	do	4.80	1,550
Sept. 24	do	4.15	1,047
Oct. 1	do	2.75	76
1897.			
Apr. 21	F. Cogswell	5.10	2,133
May 12	do	5.15	2,216
June 23	do	4.20	1,089
July 21	do	3.00	273
Aug. 25	do	3.65	92
Sept. 22	do	3.32	404
Oct. 20	do	3.35	330
1898.			
Apr. 8	A. L. Fellows	3.15	325
May 12	do	4.30	1,163
June 17	do	4.80	1,870

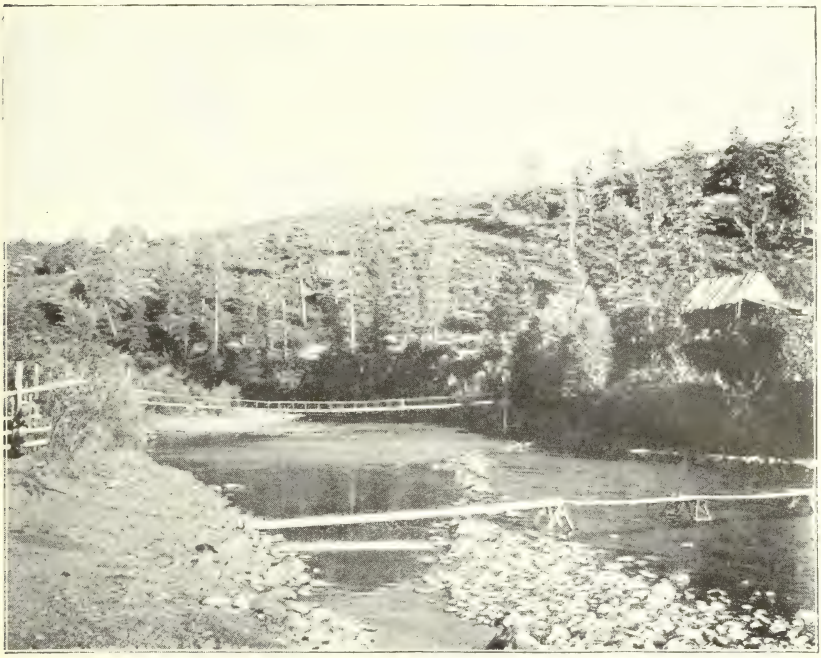
Discharge measurements made on Dolores River at Dolores—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1898.		*Feet.*	*Sec.-ft.*
Aug. 16	G. H. Matthes	2.80	102
Sept. 11	do	2.70	72
Sept. 28	do	2.55	46
Oct. 21	A. L. Fellows	2.55	40
1899.			
Apr. 20	A. L. Fellows	3.60	613
May 17	do	4.15	963
June 27	do	3.30	307
Nov. 22	do	2.70	56
1900.			
Mar. 24	A. L. Fellows	2.90	145
May 5	do	3.90	767
June 27	do	3.25	320
Aug. 11	do	2.60	31

SAN MIGUEL RIVER AT FALL CREEK.

This stream, an important tributary of the Dolores, rises in San Miguel County and drains an area immediately west of the headwaters of Uncompahgre River. The stream and its tributaries run for the most part in a northeasterly direction, and it enters the Dolores in the western part of Montrose County. A comparatively small amount of water has thus far been used for irrigation, but plans are now being developed having reference to the use of the water on a considerable scale in the western part of San Miguel County. The station is located at a wagon bridge near the railway station at Fall Creek. The channel is fairly stable and the banks are not liable to overflow. The station was discontinued in the fall of 1899.[a]

[a] For further information concerning this station see Biennial Reports of the State Engineers of Colorado. Eighth, p. 522; Ninth, p. 407; Tenth, p. 368. Also publications U. S. Geological Survey: Annual Reports. Eighteenth, Part IV, p. 264; Nineteenth, Part IV, p. 406; Twentieth, Part IV, p. 395; Twenty-first, Part IV, p. 283; Bulletin No. 140, p. 193; Water-Supply and Irrigation Papers, No. 11, p. 68; No. 16, p. 142; No. 28, pp. 137, 142, and 144; No. 38, p. 306; No. 39, p. 451. Also report on Agriculture by Irrigation, Eleventh Census, by F. H. Newell, p. 131.



A. GAGING STATION ON DOLORES RIVER AT DOLORES

B. GAGING STATION ON SAN MIGUEL RIVER AT FALL CREEK.

Discharge of San Miguel River at Fall Creek.

[Altitude, 7,466 feet; drainage area, 327 square miles.]

Month.	1895.	1896.	1897.	1898.	1899.	Mean.	Equivalent in acre-feet.	Mean run-off.	
								Second-feet per square mile.	Depth in inches.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*			
April	[b] 200	281	213	[b] 200	134	206	12,258	0.63	0.70
May	[b] 500	770	[b] 500	296	416	496	30,498	1.52	1.75
June	[b] 556	349	774	813	538	606	36,060	1.85	2.06
July	341	157	375	380	238	298	18,323	.91	1.05
August	227	65	183	133	195	161	9,900	.49	.56
September	100	176	215	89	101	136	8,093	.42	.47
October	64	82	184	50	[b] 75	91	5,595	.28	.32
November	45	57	96	40	[b] 70	62	3,689	.19	.21
Mean	254	242	318	250	221	257	124,416	.79	7.12
Acre-feet for period recorded	122,936	117,128	153,912	121,000	106,764				

[a] The run-off given is for the acre-feet for normal months with the total for a normal eight months as given, the average monthly flow per square mile with the average for the eight months, and the normal depth in inches for each month with the total depth for the normal eight months. Details may be found in the authorities cited.

[b] Estimated.

Maximum and minimum discharge and average run-off of San Miguel River at Fall Creek for that portion of each year covered by records.

Year.	Discharge.				Run-off.[a]	
	Minimum.		Maximum.		Depth in inches.	Second-feet per square mile.
	Date.	Amount.	Date.	Amount.		
		Sec.-ft.		*Sec.-ft.*		
1895	Dec. 24	6	June 29	587	0.87	0.78
1896	Nov. 7	22	May 27	2,404	.82	.74
1897	Apr. 4	52	June 16	997	1.08	.97
1898	Nov. 21	22	June 23	1,335	.84	.76
1899	Apr. 2	25	June 11	1,000	.75	.68

[a] The run-off is for the average of second-feet per square mile, and the depth in inches for thirty days at the average rate.

Discharge measurements made on San Miguel River at Fall Creek.

Date.	Hydrographer.	Gage height.	Discharge.
1895.		*Feet.*	*Sec.-ft.*
June 24	F. Cogswell	4.00	512
Aug. 27	do	3.20	205
Oct. 8	do	2.65	81
1896.			
May 12	F. Cogswell	3.75	360
June 16	do	3.45	290
July 20	do	3.15	175
Aug. 23	do	2.60	62
Sept. 22	do	2.75	85
Oct. 20	do	2.60	63
1897.			
Apr. 20	F. Cogswell	3.40	304
May 11	do	4.05	572
June 22	do	4.45	811
July 20	do	3.45	336
Aug. 24	do	2.85	145
Sept. 21	do	3.30	248
Oct. 19	do	3.05	197
1898.			
Apr. 7	A. L. Fellows	2.50	66
May 11	do	3.30	270
June 16	do	4.40	841
Aug. 13	do	2.80	133
Oct. 17	do	2.30	30

Discharge measurements made on San Miguel River at Fall Creek—Continued.

Date.	Hydrographer.	Gage height.	Discharge.
1899.		*Feet.*	*Sec.-ft.*
Apr. 18	A. L. Fellows	2.85	164
May 16	do	3.70	562
June 21	do	3.60	449
Nov. 21	do	2.35	52

MISCELLANEOUS MEASUREMENTS.

But few measurements are on record for this division, the danger of shortage having been only recently felt. Many measurements have undoubtedly been made, mostly for the purpose of ascertaining the flow with reference to development of power, but these are not, as a rule, available. Further investigations are needed in this division, as the supply of water will become of great moment before many years have elapsed. The following are, however, on record. Other measurements may also be found on page 108 et seq. of the Ninth Biennial Report of the State Engineer:

Stream measurements in Grand River division.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
1895.				*Sec.-ft.*
Oct. 22	D. R. Crosby	Grand River	Palisade	2,767
1899.				
Apr. 19	A. L. Fellows	Dolores	Rico	168
May 16	do	Fall Creek	Falls Creek	62
June 17	do	Roaring Fork	Glenwood	11,258
June 21	do	Fall Creek	Fall Creek	45
Sept. 22	do	Dolores	Rico	23
Nov. 17	do	Roaring Fork	Glenwood	457
Nov. 22	do	Dolores	Rico	16
1900.				
July 8	A. L. Fellows	Roaring Fork	Glenwood	1,570
Aug. 23	do	do	do	423

GREEN RIVER DIVISION.

DRAINAGE AND IRRIGATION.

Green River and its tributaries drain the northwestern corner of Colorado. The Green itself traverses Colorado for only a very short distance, and during its course it runs through a deep canyon, so that but little irrigation is practiced along its borders, this being on the bottom lands. It is possible, however, that a tract of land of considerable size may eventually be irrigated from this stream, in the extreme northwestern corner of the State. The principal tributaries of the Green in Colorado are Yampa and White rivers. These drain areas of considerable size and importance, in which there are vast tracts of irrigable land that will undoubtedly be eventually cultivated so far as the water supply will permit. These streams resemble the tributaries of Grand River in general, excepting that they traverse a country that is more open and rolling. Not much irrigation is now practiced except along lands immediately adjoining the stream, but a number of plans have been projected for taking the water on to the uplands, which will no doubt be eventually carried out. No permanent stations have been maintained anywhere in this division, so that all measurements on record are compiled in the following list of miscellaneous gagings. Problems relating to the use of water are, however, becoming of great moment in this part of the State, and it is important that stations should be established at as early a date as possible, at least upon the main streams.

The Green River irrigation division, as a political subdivision, comprises all lands in Colorado drained by Green River and its tributaries. The water districts of which it is composed are Nos. 43, 44, 54, 55, 56, 57, and 58. No. 43 consists of the lands irrigated by ditches taken from White River and its tributaries; No. 44 of lands irrigated by water taken from that portion of Yampa River above the mouth of Little Snake River and below the mouth of Fortification Creek, and from the tributaries to that portion of Yampa River; No. 54 of all lands lying in the State of Colorado irrigated by water taken from that portion of Little Snake River and its tributaries above the most westerly intersection of said river with the Colorado State line; No. 55 of all lands irrigated by water from the Yampa or Little Snake rivers and their tributaries below districts Nos. 44 and 55; No. 56 of Green River and tributaries in Colorado, except Yampa River; No. 57 of Yampa River and tributaries between the mouth of Fortification Creek and Elk River; and No. 58 of Yampa River and tributaries above No. 57. But little attention has thus far been paid to the priorities of water rights in these districts.[a]

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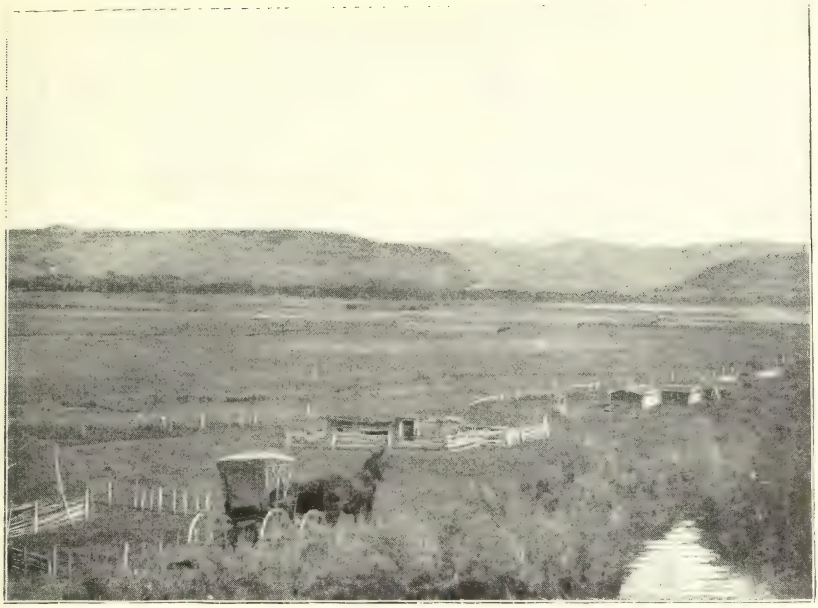
[a] For further data concerning this division, see publications U. S. Geological Survey: Ninth Annual Report, p. 677; Eighteenth, Part IV, p. 268; Nineteenth, Part IV, p. 394; Twentieth, Part IV, p. 380; Eleventh Census Irrigation Report by F. H. Newell and Bulletin No. 140, p. 200. Also Biennial Reports of the State Engineer of Colorado, Ninth, p. 409; and all biennial reports for commissioners' reports.



A. STEAMBOAT SPRINGS.

B. YAMPA RIVER VALLEY NEAR HAYDEN.

MISCELLANEOUS GAGINGS.

In the following table are given the results of gagings made in May, 1895, and September, 1898, on certain specified streams in the Green River irrigation division:

Miscellaneous gagings made in the Green River irrigation division.

Date.	Hydrographer.	Stream.	Locality.	Discharge.
1895.				*Sec.-ft.*
May 16	H. A. Sumner	White River	White River	3,047
1898.				
Sept. 14	A. L. Fellows	White River	Meeker	300
Sept. 15	do	Williams River	Hamilton	25
Sept. 17	do	Yampa River	3 miles below Hayden	111
Do.	do	Elk River	Trull	63
Sept. 18	do	Yampa River	Steamboat Springs	65
Sept. 19	do	Snake River	Honnold	17
Sept. 20	do	Slater Fork	Slater	9
Sept. 21	do	Snake River	Dixon, Wyo	19
Sept. 22	do	Yampa River	Below Maybell	99
Sept. 24	do	Green River	Ladore	552
Sept. 26	do	Yampa River	Craig	79

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Fellows (A. L.).

Water-Supply and Irrigation Paper No. 74 Series I, Irrigation, 14 | Department of the interior | United States geological survey | Charles D. Walcott, director | — | Water resources | of the | State of Colorado | by | A. L. Fellows | [Vignette] | Washington | government printing office | 1902

8°. 151 pp., 14 pls.

Subject.

Water-Supply and Irrigation Paper No. 74 Series I, Irrigation, 14 | Department of the interior | United States geological survey | Charles D. Walcott, director | — | Water resources | of the | State of Colorado | by | A. L. Fellows | [Vignette] | Washington | government printing office | 1902

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Water-Supply and Irrigation Paper No. 75 Series P, Hydrographic Progress Reports, 19

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

REPORT

OF

PROGRESS OF STREAM MEASUREMENTS

FOR

THE CALENDAR YEAR 1901

BY

F. H. NEWELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 30, 1902.

SIR: I have the honor to transmit herewith a manuscript for a paper descriptive of the results of hydrographic surveys made during the calendar year 1901. This paper may be considered as being the third and last part of the Annual Report of the Division of Hydrography for 1901, Parts I and II having been printed as Water-Supply Papers Nos. 65 and 66, giving the gage heights and measurements at various river stations maintained during 1901. This form of publication has resulted from the limitations formerly imposed by law and through the operation of recent changes which have been made. At the time that Paper No. 65 was put in type it was proposed to print the manuscript herewith presented as Part IV of the Twenty-third Annual Report. By act of May, 1902, the report of the Director was limited to one volume, and the restriction of Water-Supply Papers to 100 pages was removed. As a result, the material which otherwise would have appeared as one of the volumes of the Director's report is now presented for publication in the Water-Supply and Irrigation series.

This paper presents briefly the results of computations of river flow, the data for them having been presented in Water-Supply Papers Nos. 65 and 66. This separation of the original observations of gage height and river measurement was brought about by the fact that since 1895 it has been found desirable to print as soon as possible after the conclusion of each calendar year the tables of gage heights and related facts, reserving for the annual report of the Director the conclusions resulting from computations and the diagrams of discharge, together with maps and other illustrations. This plan is carried out for 1901, with the exception of the modification noted in the first paragraph. It is proposed, however, in the future to combine and publish together the original observations and results for each locality.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

HON. CHARLES D. WALCOTT,
Director United States Geological Survey.

PROGRESS REPORT OF STREAM MEASUREMENTS FOR THE CALENDAR YEAR 1901.

By F. H. Newell.

GENERAL STATEMENT.

The determinations of the water supply of various parts of the United States have been continued during the year 1901 by the Division of Hydrography in a manner similar to that of previous years, slight modifications and improvements having been introduced in methods and operations. The work consists in measuring the streams and estimating the water supply, both above and under ground. To give full facts concerning the water supply it is necessary not merely to ascertain the quantity, but also in many cases the quality, and especially the possibilities of water storage or conservation. Water can not be considered as a resource unless it can be had when needed, and therefore the determination of the practicability of holding the floods until time of drought underlies any statement of water supply. In a similar way when considering underground waters it is not enough to know that there is water beneath the surface, but the facts must be ascertained as to the depth to the water, the rate of movement, if any, and the possibility of bringing the water to the surface at reasonable cost.

The principal operation of the hydrographic surveys, as at present conducted, is that of measuring the waters flowing upon the surface, obtaining their fluctuations in quantity, and sometimes in quality, from month to month and from year to year. The points at which the principal systematic measurements were made during the year 1901 are shown in figs. 1 and 2 by the heavy dots upon the branching lines of river systems.

HISTORICAL REVIEW.

Under the operation of various resolutions of Congress and appropriation acts, systematic hydrographic measurements have been carried on by the Geological Survey since 1888, papers Nos. 65, 66, and 75, taken together, constituting what may be termed the annual report

for the fourteenth year of the water supply and irrigation survey. The hydrographic data obtained during these years are scattered through a number of publications. In order to facilitate reference to these,

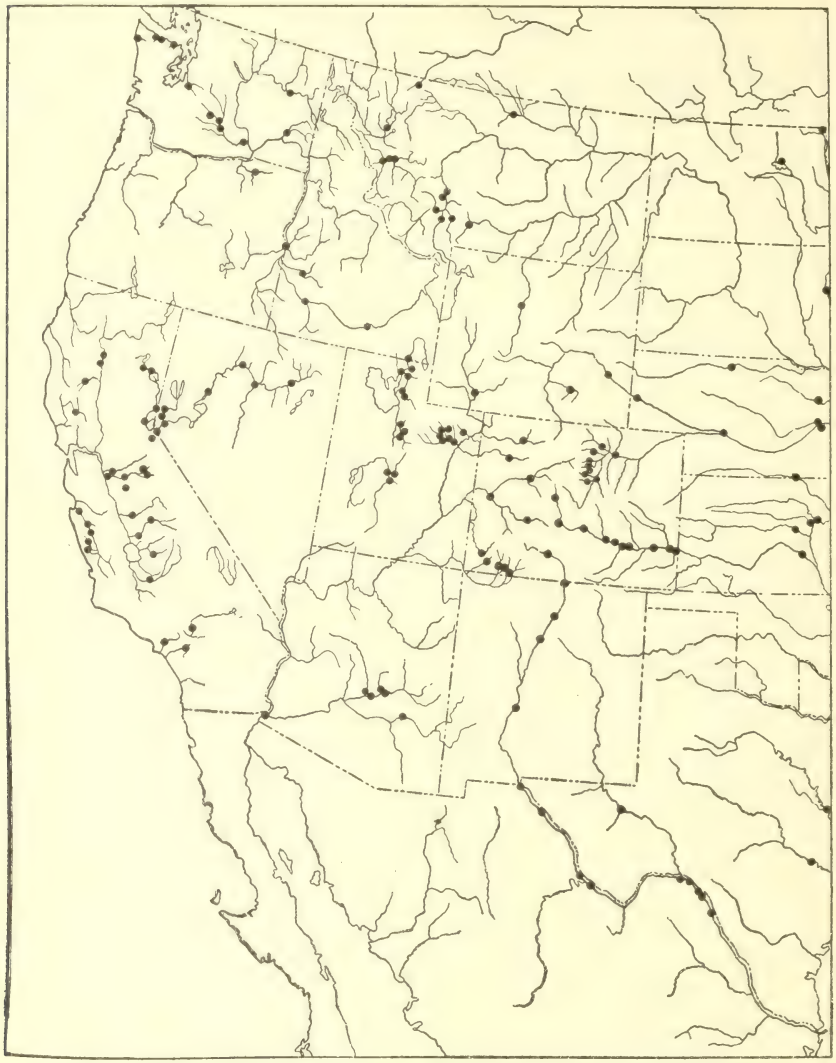


FIG. 1.—Location of river stations in western half of the United States in 1901.

the following brief review is given of the progress of the investigation, showing in chronologic order the development of the work:

1888, first year.—The Irrigation Survey was organized in accordance with the provisions of the act of October 2, 1888. The results of the first year's work are given in the Tenth Annual Report of the Geological Survey, Part II, Irrigation. This volume is devoted mainly to the details of organization and of the plans adopted and partly executed.

1889, second year.—The results of the operations outlined in the report just named are given in the Eleventh Annual Report, Part II, Irrigation. This contains a discussion of the hydrography and of the

FIG. 2.—Location of river stations in eastern half of United States in 1901.

engineering surveys for canals and reservoirs, the statement of the Director of the Geological Survey to the House Committee on Irrigation, a report upon the topographic surveys relating to reclamation work, and a list of irrigation literature.

1890, third year.—The results of operations are given in the Twelfth Annual Report, Part II, Irrigation. This contains a statement of the location and survey of reservoir sites, by A. H. Thompson; a paper

on the hydrography of the arid region, by F. H. Newell, and a discussion of irrigation in India, by Herbert M. Wilson.

1891, fourth year.—The discussion of results obtained is continued in the Thirteenth Annual Report, Part III, Irrigation. This consists of a paper upon water supply for irrigation, by F. H. Newell; two papers by Herbert M. Wilson, the first upon American irrigation engineering and the second upon the engineering results of the Irrigation Survey, and a report by A. H. Thompson upon the location and survey of reservoir sites during the fiscal year.

1892, fifth year.—The Fourteenth Annual Report, Part II, contains a paper entitled "The results of stream measurements," by F. H. Newell. With this are two others bearing upon hydrography, the first, entitled "Potable waters of eastern United States," by W J McGee; the second, "Natural mineral waters of the United States," by A. C. Peale.

1893, sixth year.—The results of field work during this year are shown in Bulletin No. 131.

1894, seventh year.—The operations of this year are also shown in Bulletin No. 131. The Sixteenth Annual Report, Part II, contains a paper entitled "The public lands and their water supply," by F. H. Newell. This gives in condensed form the results of hydrographic work in preceding years. There is also in the same volume a report on the "Water resources of a portion of the great plains," by Robert Hay.

1895, eighth year.—Bulletin No. 140, entitled Report of Progress of the Division of Hydrography, gives the results of field work during the greater part of this year. The Seventeenth Annual Report contains a paper by G. K. Gilbert on the "Underground waters of the Arkansas Valley in eastern Colorado;" one by Frank Leverett on the "Water resources of Illinois," and another, by N. H. Darton, on "Artesian waters of a portion of the Dakotas."

1896, ninth year.—For this year was begun the method of double publication, the gage heights being published in Water-Supply Paper No. 11, and the results of computations, the illustrations, etc., being given in the Eighteenth Annual Report, Part IV.

1897, tenth year.—The gage heights are given in Water-Supply and Irrigation Papers Nos. 15 and 16 and the detailed descriptions in the Nineteenth Annual Report, Part IV.

1898, eleventh year.—The operations at river stations are given in Water-Supply Papers Nos. 27 and 28, while the results are shown in the Twentieth Annual Report, Part IV.

1899, twelfth year.—The operations at river stations are contained in Water-Supply Papers Nos. 35 to 39, inclusive, and the discussion of results in the Twenty-first Annual Report, Part IV.

1900, thirteenth year.—The operations at river stations are given in Water-Supply Papers Nos. 47 to 52, inclusive, while the final tables

and illustrations are shown in the Twenty-second Annual Report, Part IV.

1901, fourteenth year.—The operations at river stations are given in Water-Supply Papers Nos. 65 and 66, while the conclusions, with illustrations, are shown in Water-Supply Paper No. 75 instead of Part IV of the Twenty-third Annual Report, this latter report being confined to one volume.

The hydrographic surveys have been from necessity confined to the United States proper, but urgent appeals have been received for similar work in southern Alaska, the Hawaiian Islands, and other outlying possessions. The rivers of southern Alaska have considerable value as sources of water power and will probably be utilized in the future in connection with mining operations and the reduction of ores. The vast extent of Alaska and the public lands, some of which have great value from their mineral resources, are little realized, and it is only when the area of Alaska is compared with that of the States of the Union that comprehension can be had of the extent of land surface and area over which mineral and water resources are distributed.

ACKNOWLEDGMENTS.

Most of the measurements presented in Papers 65, 66, and in this paper have been obtained through local hydrographers, a comparatively small portion of the work having been conducted directly from the office of the Geological Survey at Washington. Acknowledgment is due to each of these persons, and thanks are extended to other persons and to corporations who have assisted the local hydrographers or have cooperated in any way, either by furnishing records of the height of water or by assisting in transportation. The following list, arranged alphabetically by States, gives the names of the resident hydrographers:

California: J. B. Lippincott, civil engineer, Los Angeles.

Colorado: A. L. Fellows, civil engineer, Denver.

Georgia and Alabama: Prof. B. M. Hall, civil engineer, Atlanta; Prof. W. S. Yeates, State geologist, Atlanta; and Prof. Eugene A Smith, State geologist, Tuscaloosa.

Idaho: N. S. Dils, civil engineer, Caldwell.

Kansas: W. G. Russell, Russell.

Maryland: Prof. W. B. Clark, State geologist, Baltimore.

Montana: Prof. Samuel Fortier and J. S. Baker, Bozeman.

Nebraska: Prof. O. V. P. Stout, State University, Lincoln, assisted by Adna Dobson and Glenn E. Smith.

Nevada: L. H. Taylor, civil engineer, Carson City.

New Mexico: P. E. Harroun, civil engineer, Albuquerque.

North and South Carolina: Prof. J. A. Holmes, State geologist, Chapel Hill, N. C., assisted by E. W. Myers.

Texas: Prof. Thomas U. Taylor, State University.

Utah: Prof. George L. Swendsen, Logan.

Virginia and West Virginia: Prof. D. C. Humphreys, Washington and Lee University, Lexington, Va.

Washington: Sydney Arnold, civil engineer, North Yakima.

Wyoming: A. J. Parshall, civil engineer, Cheyenne.

In Colorado the State engineering department (Mr. A. J. McCune in charge) has cooperated, and valuable assistance has been rendered by the Denver and Rio Grande, the Union Pacific, the Colorado and Southern, the Rio Grande Southern, the Atchison, Topeka and Santa Fe, and the Burlington and Missouri River railroads. Special thanks are also due to the officers and employees of The Great Plains Water Company, one of whose engineers, Mr. C. W. Beach, has made many measurements on the Arkansas; to the Amity Land and Canal Company and its chief engineer, Mr. Thomas Berry; to the Buffalo Canal Company; to Mr. C. L. Harrison, chief engineer of the Denver Union Water Company; to Messrs. S. M. Matlock, T. J. Burrows, J. M. Wolaver, L. H. Dickson, Thomas Kneale, W. E. Obert, and other water commissioners in various parts of the State, and to many others who have furnished valuable information.

In California assistance in transportation has been rendered by Mr. William Hood, chief engineer of the Southern Pacific Company, who has also procured the assistance of bridge watchmen in observing the height of water in the rivers. Mr. Walter James, chief engineer of the Kern County Land Company, has supplied records of Kern River, and Mr. A. K. Warren, assistant engineer, has also furnished information. Mr. H. F. Parkinson, superintendent of canals taking water from San Gabriel River above Azusa, has furnished records of that stream; Mr. T. F. Keefe, secretary of the Fontana Development Company, has furnished records of Lytle Creek; and Mr. K. Sanborn, engineer of the Riverside Water Company, rendered valuable assistance in making low-water measurements. Mr. W. G. Nevin, general manager of the Southern California Railroad, has furnished transportation over the Santa Fe lines in California. The Los Angeles City Water Company has maintained gagings of Los Angeles River, which, through the courtesy of Mr. William Mulholland, city engineer, have been furnished to the Survey without charge. Mr. H. N. Savage, chief engineer, of the San Diego Land and Town Company, has contributed information concerning Sweetwater River.

In Georgia, Alabama, Florida, Tennessee, and Mississippi Prof. B. M. Hall and Mr. Max Hall, resident hydrographers, have been assisted in their work by the following persons and corporations: Prof. W. S. Yeates, State geologist of Georgia, has paid the observers at Madison, Tallulah Falls, Juliette, Almon, and Blueridge, and for a portion of the year the observers at Carters, Canton, and Woodbury. Dr. Eugene A. Smith, State geologist of Alabama, has paid the observers at Riverside, Cordova, Milstead, Susanna, Sturdivant, Dadeville, Alex-

ander, and Nottingham. The city of Augusta maintains the station at Augusta, Ga. The officials of the United States Weather Bureau have shown a great interest in the work and have rendered valuable assistance, particularly Messrs. J. B. Marbury, D. Fisher, F. P. Chaffee, L. M. Pindell, W. M. Dudley, and T. S. Collins. They have maintained stations at Calhoun Falls, S. C.; at Carlton, Dublin, Albany, West Point, and Oakdale, in Georgia; at Montgomery and Selma, in Alabama, and at Chattanooga and Knoxville, in Tennessee; and for a part of the year stations at Woodbury, Canton, Resaca, and Rome, in Georgia, and at Charleston, Tenn. Acknowledgments are also due to Messrs. R. C. McCalla, D. M. Andrews, and G. T. Nelles, United States assistant engineers, for cooperation in the work by sending records of stations at Tuscaloosa, Ala., and Lincoln, Ala., and furnishing valuable data concerning the Coosa, Cahaba, Warrior, Tennessee, and other rivers. Also to Prof. C. M. Strahan, of Georgia University; to Prof. C. S. Wilkins, of Alabama University; to Prof. W. M. Fulton, of Tennessee University; to Mr. H. S. Weems, of Carters, Ga.; and to Mr. W. M. Towers, of Rome, Ga. Transportation has been furnished through the kindness of Mr. J. S. B. Thompson, general agent of the Southern Railway; Mr. E. St. John, vice-president and general manager of the Seaboard Air Line; Mr. Thomas K. Scott, general manager of the Georgia Railroad; Mr. John M. Egan, president of the Central of Georgia Railway; Mr. James T. Wright, president and general manager of the Macon, Dublin and Savannah Railroad; Mr. John B. Newton, general manager of the Atlanta, Knoxville and Northern Railway; Mr. W. B. Denham, general superintendent of the Plant System; Mr. C. A. Wickersham, president and general manager of the Atlanta and West Point Railway and the Western Railway of Alabama; Mr. Hunter McDonald, chief engineer of the Nashville, Chattanooga and St. Louis Railway; Mr. Y. van den Berg, vice-president of the Louisville and Nashville Railroad, and Mr. J. T. Harahan, second vice-president of the Illinois Central Railroad.

Thanks are due to the Norfolk and Western Railway for an annual pass over all lines in Virginia and West Virginia, issued to Prof. D. C. Humphreys, and to the Chesapeake and Ohio Railway for a similar courtesy during the months of July, August, and September. Thanks are also due to Mr. Charles S. Churchill, of Roanoke, Va., for suggestions and assistance.

In Idaho the State engineer, Mr. D. W. Ross, has heartily cooperated. Transportation has also been furnished to Mr. N. S. Dils and others in the employ of the Survey, through the kindness of Mr. D. E. Burley, general passenger and ticket agent of the Oregon Short Line.

In connection with the work in Kansas the Survey is under obligations to the Missouri, Kansas and Texas Railway, the Union Pacific

Railway, and the Santa Fe Railroad for transportation furnished t Mr. W. G. Russell, resident hydrographer.

In Montana assistance has been rendered by the Great Norther Railroad, by the Bitterroot Stock Farm, of Hamilton; by Prof. M. J Elrod, of Missoula University; by J. D. O'Donnell, of Billings, and b Mr. J. L. Rhead, superintendent of the Big Ditch at Laurel, Mont.

In Nebraska the resident hydrographer, Prof. O. V. P. Stout, ha had the benefit of the continued cooperation of various public an private organizations. Special acknowledgments are due to the agr cultural experiment station and the State board of irrigation for th service of hydrographers, to the State board of agriculture for th preparation and publication of valuable data, and to the followin railway officials, without whose assistance the amount of work accom plished would have been greatly lessened: Mr. G. W. Holdredge, gen eral manager of the Burlington lines west of Missouri River; Mr George F. Bidwell, general manager of the Fremont, Elkhorn and Mis souri Valley Railroad, and Mr. E. L. Lomax, general passenger agen of the Union Pacific Railroad; also to Prof. A. B. Crane, of the Sout Dakota Agricultural College, for measurements of Big Sioux River.

In Nevada officials of the Southern Pacific Railroad Company, o the Nevada-California-Oregon Railway Company, and of the Lak Tahoe Railway and Transportation Company have furnished transpor tation to Mr. L. H. Taylor, enabling him to greatly extend his fiel work.

In Wyoming transportation has been furnished to Mr. A. J. Par shall by Mr. E. Dickinson, general manager of the Union Pacific Rail road; by Mr. G. W. Holdredge, general manager of the Burlington an Missouri Railroad; by Mr. George F. Bidwell, general manager of th Fremont, Elkhorn and Missouri Valley Railroad, and by Mr. Fran Trumbull, general manager of the Colorado and Southern Railway thus greatly increasing the amount of work accomplished.

In Washington the work has been facilitated by transportation fur nished to Mr. Sydney Arnold by Mr. Thomas Cooper, general man ager of the Northern Pacific Railway.

NORTHERN ATLANTIC COAST DRAINAGE.

Under this heading have been included data pertaining to the river entering the Atlantic Ocean from Maine to Virginia, inclusive, a arbitrary line being drawn between James River and Roanoke River the latter stream being included in the southern Atlantic coas drainage.

In order to systematize the work of stream gaging in Maine, perma nent gaging stations were established during the season of 1901 by th Geological Survey on a number of rivers in the State of Maine tha are of peculiar interest on account of their water powers. Practically all of the data heretofore published on the Maine streams have bee

furnished through the courtesy of local engineers and milling companies from their own records. As the data obtained at the newly established stations are as yet too incomplete to warrant computation of the discharge at these points, no results of measurements are given for 1901. As in preceding years, records of daily discharge have been kept by the Forest Paper Company at Yarmouthville, Me., on Cobbosseecontee River, at the reservoir dam, near Augusta; by the Rumford Falls Power Company, at Rumford Falls, on Androscoggin River, and by Mr. Hiram F. Mills, of Lowell, Mass., on Presumpscot River, at the outlet of Sebago Lake. The results of these measurements for 1901 are given in the following pages, where are also given results of observations made on Penobscot River at Sunk Haze Rips, near Costigan, Me., for the years 1899 and 1900. A full description of the Maine rivers and their drainage basins, together with tabulated statements of their flow, has been published in Water Supply Paper No. 69, entitled "Water Powers of the State of Maine," by H. A. Pressey.

Measurements of streams in New York State have been made as in previous years with the cooperation of the State engineer and surveyor, Edward A. Bond, and the deputy State engineer and surveyor, William Pierson Judson, under the immediate supervision of Robert E. Horton. The majority of these stations were primarily established in connection with a study for the water supply of the New York State canals and the Upper Hudson storage survey. The gage records for 1901 and tabulated results by months for the entire period of observation for each station have been published in Water-Supply Paper No. 65. During 1901 additional stations were established through cooperation of the department of water supply of New York, George W. Birdsall, chief engineer, for studying the possible sources of future municipal water supply for Greater New York. These stations are located as follows: Dover Plains, on Tenmile River; South Cairo, on Catskill Creek; Kingston, on Esopus Creek; New Paltz, on Wallkill River; Rosendale, on Rondout Creek; Glenham, on Fishkill Creek; and Gaylordsville, on Housatonic River. With the exception of the last-named station, which is in Connecticut, the stations are all within the State of New York. Descriptions of these stations, together with records of gage heights and results of measurements of the streams made in June, 1901, by H. A. Pressey and R. E. Horton, are published in Water-Supply Paper No. 65, pages 59–90.

Following is a complete list of the gaging stations maintained during the past season in the State of New York:

Raquette River at Hannawa Falls.
Black River at Watertown.
Black River at Felts Mills.
Beaver River at Tisses Bridge.
Indian River at Indian Lake Dam.
Schroon River at Warrensburg.
Moose River at Moose River.
Salmon River at Pulaski.
Oswego River at Fulton (High Dam, Minetto Station).
Seneca River at Baldwinsville.
Skaneateles Outlet at Willow Glen and Jordan.
Genesee River at Rochester.

Oneida River at Brewerton.
West Branch Fish Creek at McConnellsville.
Chittenango Creek at Bridgeport.
Chittenango Creek at Chittenango.
Oneida Creek at Kenwood.
Mohawk River at Ridge Mills.
West Canada Creek at Twin Rock Bridge.
Oriskany Creek at Woods road bridge.
Saquoit Creek at New York Mills.
Mohawk River at Utica.
West Canada Creek at Middleville.
Mohawk River at Little Falls.
East Canada Creek at Dolgeville.
Cayadutta Creek at Johnstown.
Hudson River at Fort Edward.
Schoharie Creek at Fort Hunter.
Schoharie Creek at Millpoint Aqueduct.
Schoharie Creek at Schoharie Falls.
Mohawk River at Schenectady.
Mohawk River at Rexford Flats.
Hudson River at Mechanicville.
Mohawk River at Dunsbach Ferry.
Normanskill Creek at French's Mill.
Kinderhook Creek at East Nassau and Wilson's dam.
Catskill Creek at South Cairo.
Esopus Creek at Kingston.
Rondout Creek at Rosendale.
Wallkill River at New Paltz.
Fishkill Creek at Glenham.
Rondout Creek at Honk Falls.
Croton River at old Croton dam.
Chenango River at Binghamton.
Susquehanna River at Binghamton.
Tenmile River at Dover Plains.
Richelieu River at Fort Montgomery.

NEW ENGLAND STREAMS.

Estimated monthly discharge of Penobscot River near Costigan, Me.

[Drainage area, 7,450 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
October	5,100	2,330	2,764	0.31	0.36
November	14,000	3,300	7,170	.96	1.07
December	11,500	4,800	9,014	1.21	1.40
1900.					
January	35,400	9,500	14,876	2.00	2.31
February	52,400	26,200	37,262	5.00	5.21
March	62,700	29,200	43,828	5.88	6.77
April	75,100	36,600	52,407	7.03	7.84
May	74,700	44,200	56,632	7.60	8.76
June	41,600	7,800	20,435	2.74	3.06
July	21,400	11,300	13,769	1.85	2.13
August	14,100	4,850	10,722	1.44	1.66
September 1–21			4,507	.60	.47

NOTE.—Daily discharge for 1899 and 1900 is given in Water-Supply Paper No. 65, pages 14 and 15.

EDWARD WARE'S MILL AT WINSLOW, ME., DURING SPRING FLOOD ON KENNEBEC RIVER.

Estimated monthly discharge of Cobbosseecontee River near Augusta, Me.

[Drainage area, 230 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	250	220	231	1.00	1.15
February	220	120	173	.75	.78
March	1,404	120	344	1.50	1.73
April	3,205	260	2,046	8.90	9.93
May	483	26	290	1.26	1.45
June	510	280	306	1.33	1.48
July	280	280	280	1.22	1.41
August	280	280	280	1.22	1.41
September	280	270	274	1.19	1.33
October	270	250	252	1.10	1.27
November	250	220	246	1.07	1.19
December	2,700	220	526	2.29	2.64
The year	3,205	26	437	1.90	25.77

NOTE.—Daily discharge for 1891 is given in Water-Supply Paper No. 65, page 20.

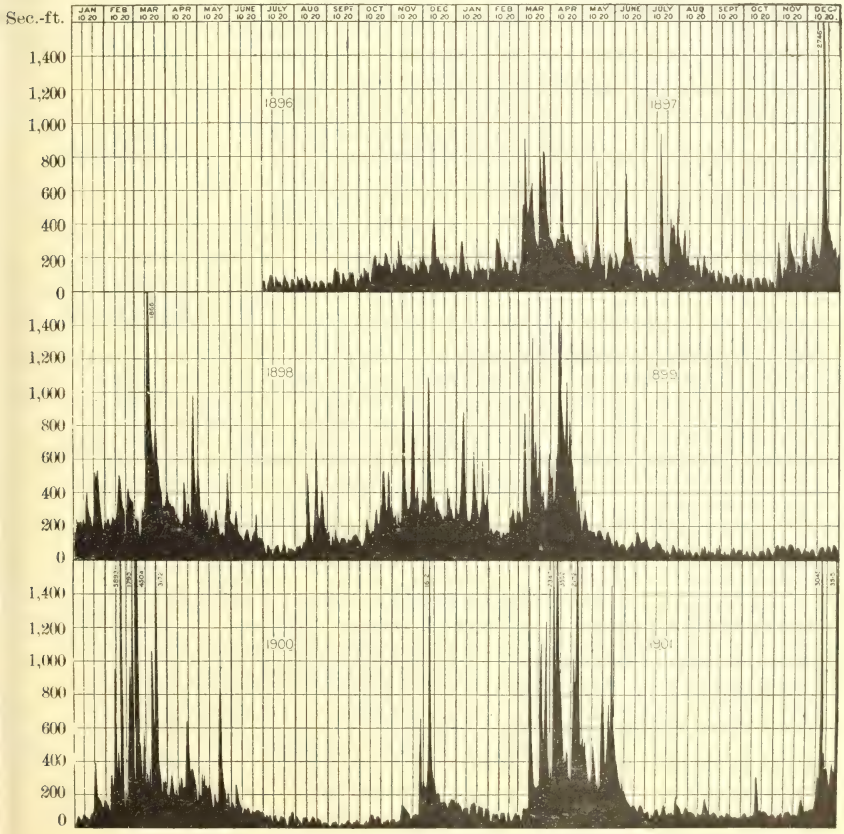


FIG. 3.—Discharge of Nashua River at Clinton, Mass., 1896–1901.

Estimated monthly discharge of Androscoggin River at Rumford Falls, Me.

[Drainage area, 2,320 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,082	1,692	1,895	0.82	0.95
February	2,496	1,563	1,832	.79	.82
March	4,445	1,873	2,463	1.06	1.22
April	32,653	2,887	14,891	6.42	7.16
May	16,808	6,711	10,714	4.62	5.32
June	7,424	2,787	4,420	1.91	2.13
July	3,833	1,612	2,671	1.15	1.33
August	5,035	1,925	2,788	1.20	1.38
September	1,955	1,343	1,590	.69	.77
October	5,137	1,547	2,224	.96	1.11
November	1,829	1,205	1,606	.69	.77
December	27,785	1,209	3,441	1.48	1.71
The year	32,653	1,205	4,211	1.82	24.67

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 21.

Estimated monthly discharge of Presumpscot River at outlet of Sebago Lake Maine.

[Drainage area, 470 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	673	367	619	1.32	1.52
February	673	517	649	1.38	1.44
March	833	333	623	1.33	1.53
April	673	0	466	.99	1.10
May	728	333	605	1.29	1.49
June	993	400	722	1.54	1.72
July	747	300	670	1.43	1.65
August	693	300	575	1.22	1.41
September	673	300	596	1.27	1.42
October	687	283	574	1.22	1.41
November	717	233	618	1.31	1.46
December	700	200	616	1.31	1.51
The year	993	0	611	1.30	17.66

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 22.

A. STREET SCENE IN MADISON, ME., DURING FRESHET ON KENNEBEC RIVER.

B. DESTRUCTION OF PROPERTY AT SKOWHEGAN, ME., BY FRESHET ON KENNEBEC RIVER.

Estimated monthly discharge of Connecticut River at Orford, N. H.

[Drainage area, 3,050 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
August 6–31			2,326	0.76	0.75
September	2,600	945	1,414	.46	.51
October	11,378	1,952	4,317	1.42	1.64
November	13,798	1,653	7,016	2.30	2.56
December	6,780	3,988	5,051	1.66	1.91
1901.					
January			[a] 3,500	1.15	1.33
February			[a] 3,300	1.08	1.12
March			[a] 5,849	1.92	2.21
April	23,478	10,228	17,972	5.89	6.57
May	13,919	5,486	8,769	2.88	3.32
June	7,990	2,686	5,186	1.70	1.90
July	8,111	1,340	3,334	1.09	1.26
August	6,540	1,205	3,642	1.19	1.37
September	2,188	1,205	1,644	.54	.60
October	5,148	1,393	2,302	.75	.86
November	2,432	1,393	1,701	.56	.62
December			[a] 6,594	2.16	2.49
The year			5,149	1.74	23.65

[a] Approximate; river frozen.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 29; rating table on page 318 of same paper.

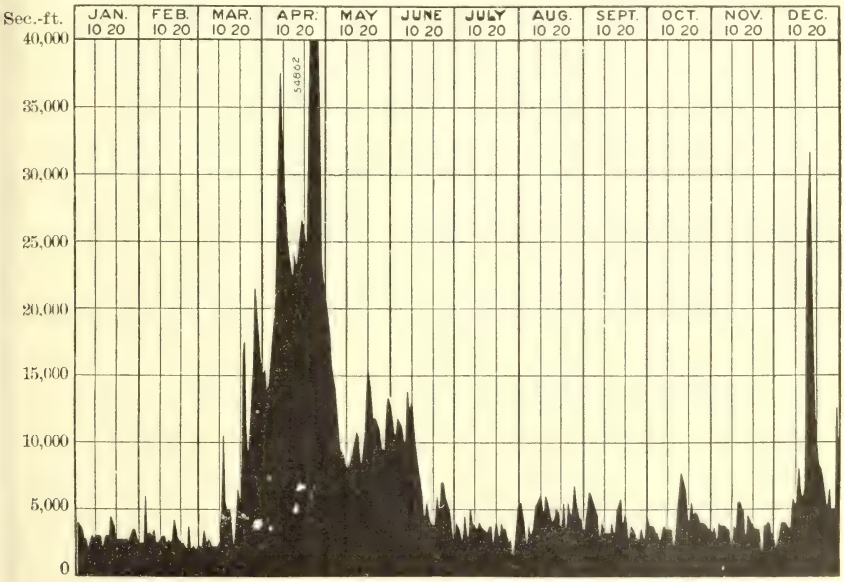


FIG. 4.—Discharge of Hudson River at Mechanicville, N. Y., 1901.

Estimated monthly discharge of Housatonic River at Gaylordsville, Conn.

[Drainage area, 1,020 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
October 23–31	.....	.....	358	0.35	0.12
November	550	240	909	.89	.99
December	3,890	810	1,544	1.51	1.74
1901.					
January	1,700	508	890	.87	1.00
February	682	324	489	.48	.50
March	16,845	458	4,269	4.19	4.84
April	12,285	2,600	6,280	6.16	6.87
May	6,525	2,600	4,432	4.34	5.01
June	4,845	745	2,067	2.03	2.26
July	885	508	674	.66	.76
August	6,285	458	1,458	1.43	1.65
September	1,700	745	1,088	1.07	1.19
October	6,045	745	1,639	1.61	1.86
November	2,035	562	1,108	1.09	1.22
December	12,525	745	3,872	3.80	4.39
The year	16,845	324	2,356	2.31	31.55

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 88; rating table on page 318 of same paper.

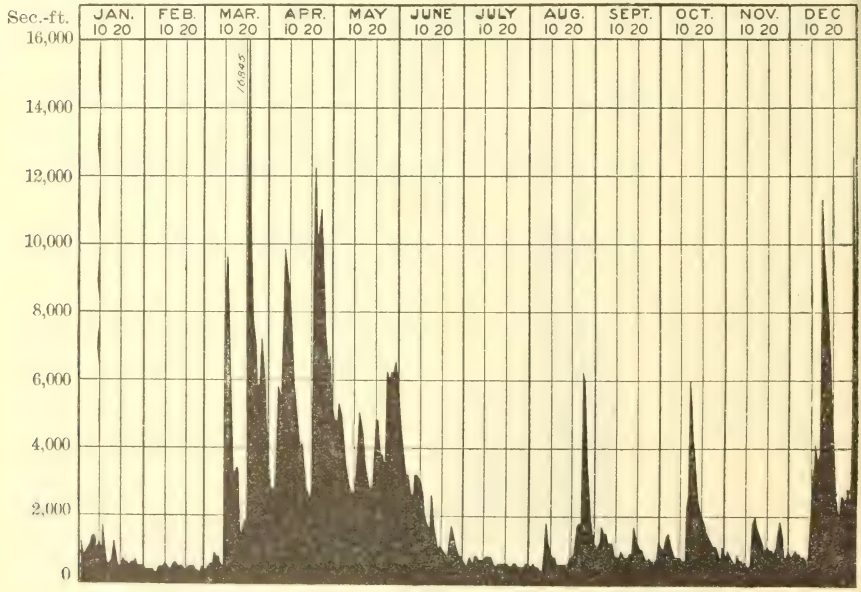
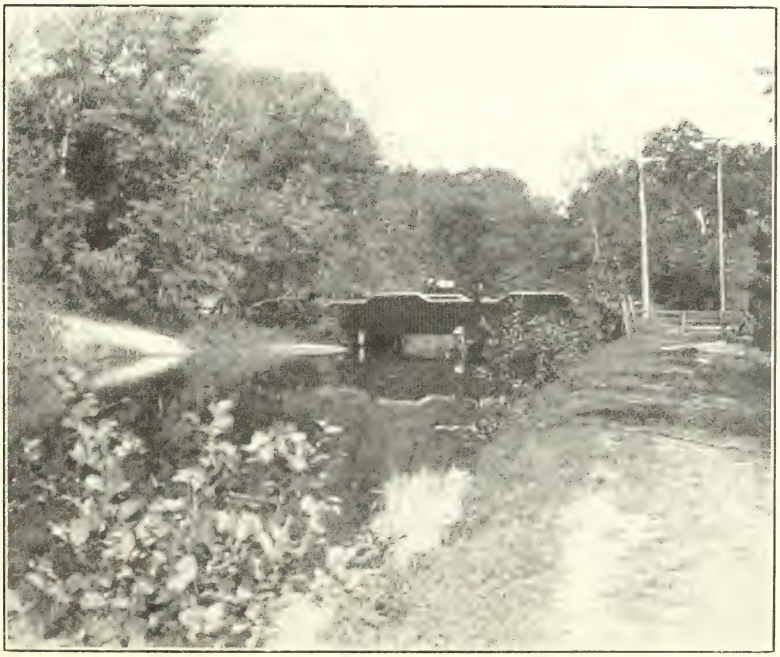


FIG. 5.—Discharge of Housatonic River at Gaylordsville, Conn., 1901

A. BLACKSTONE RIVER AT BERKELEY, R. I.



B. BLACKSTONE CANAL AT BERKELEY, R. I.

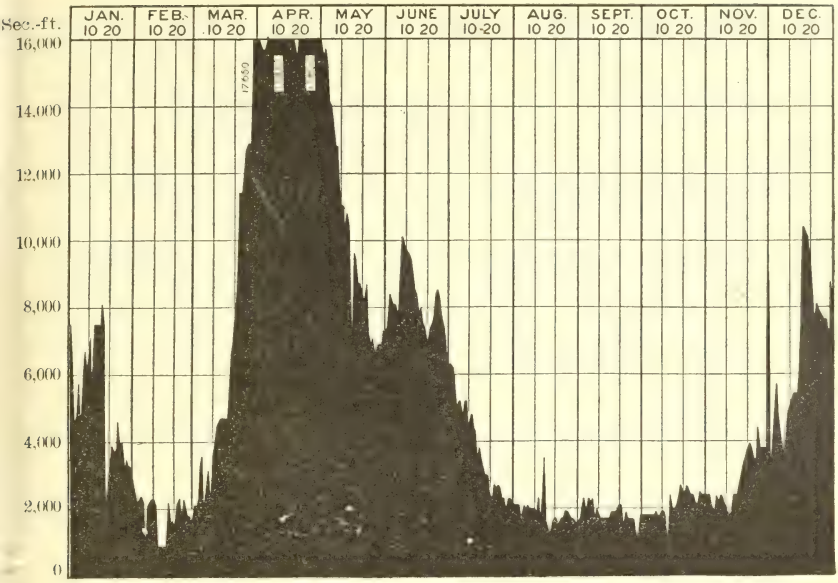


FIG. 6.—Discharge of Oswego River at high dam, New York, 1901.

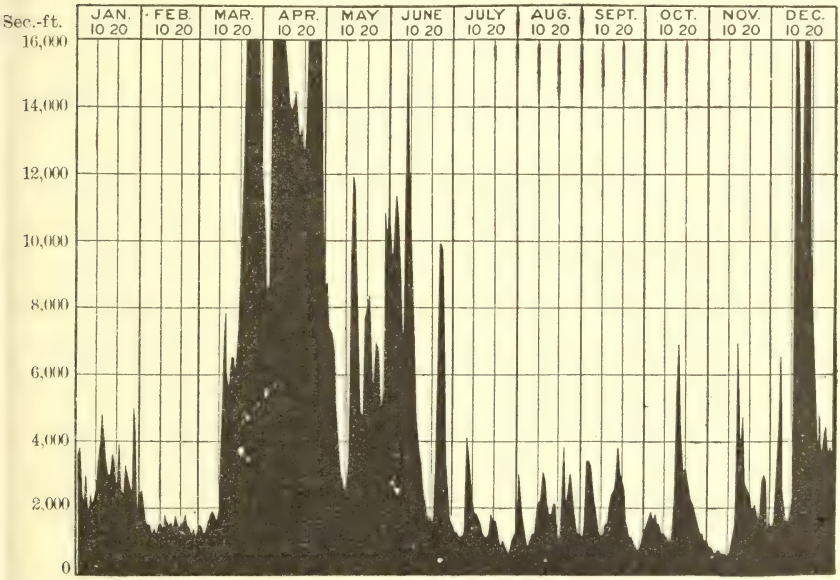


FIG. 7.—Discharge of Mohawk River at Schenectady, N. Y., 1901.

PASSAIC RIVER BASIN.

Gaging stations were established during 1901 on the Passaic River and on Pompton River, its principal tributary, at Two Bridges, N. J., by George B. Hollister, under whose direction systematic measurements are now being carried on. The two rivers drain areas of the

same extent, though different in character, the Pompton draining the high lands of northern New Jersey and part of New York State, while the Passaic flows through comparatively level lands. Following are the results of measurements for 1901:

Estimated monthly discharge of Passaic River at Two Bridges, N. J.

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,000	623	1,105	3.07	3.54
June 1–22			779	2.16	1.76
July	1,007	137	448	1.24	1.43
August	3,858	363	1,409	3.91	4.51
September	1,650	271	632	1.76	1.96
October	959	225	472	1.31	1.51
November	719	181	321	.89	.99
December	4,445	225	1,015	2.82	3.26

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 211; rating table on page 318 of same paper.

Estimated monthly discharge of Pompton River at Two Bridges, N. J

[Drainage area, 360 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May [a]	2,751	893	1,529	4.25	4.90
June 1–22			1,015	2.82	2.30
July	1,254	195	541	1.50	1.73
August	5,342	255	1,834	5.09	5.86
September	2,240	221	848	2.35	2.62
October	1,181	221	533	1.48	1.71
November	1,001	195	322	.89	.99
December	6,328	300	1,441	4.00	4.61

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 212; rating table on page 318 of same paper.

A. TRENTON FALLS GORGE ON WEST CANADA CREEK, NEW YORK.

B. GAGING CATSKILL CREEK AT CAIRO, N. Y.

DELAWARE RIVER AND TRIBUTARIES NEAR PHILADELPHIA.

The gaging station on this river was established July 23, 1897, at Lambertville, N. J. Since its establishment continuous records have been kept of the flow of the river, which have been published in the annual reports, commencing with the Twentieth Annual Report, Part IV. The figures of discharge include in every instance the flow of the Delaware and Raritan Canal feeder. The record for 1901 is published herewith. Measurements of the flow of Perkiomen, Wissahickon, Tohickon, and Neshaminy creeks, all tributaries of Delaware River near Philadelphia, have been continued, as in former years, by Mr. John E. Codman, in charge of the hydrographic work of the bureau of water of the city of Philadelphia. The location of these creeks and the points of measurement are shown in fig. 16 of the Twentieth Annual Report, Part IV, page 89. On the following pages are given the records of these streams for 1901.

Estimated monthly discharge of Delaware River at Lambertville, N. J.

[Drainage area, 6,855 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	16,325	2,300	6,192	0.90	1.04
February			[a] 2,500	.37	.39
March	74,890	2,600	23,268	3.39	3.91
April	64,075	15,475	31,811	4.64	5.17
May	65,620	14,625	24,524	3.58	4.13
June	48,110	5,300	16,902	2.47	2.75
July	10,000	1,825	4,676	.68	.78
August	69,740	2,300	16,285	2.38	2.75
September	21,200	5,300	10,785	1.57	1.75
October	18,050	5,550	9,542	1.39	1.60
November	10,800	4,320	6,680	.97	1.08
December	161,410	6,375	31,366	4.58	5.28
The year			15,377	2.24	30.63

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 214; rating table on page 318 of same paper.

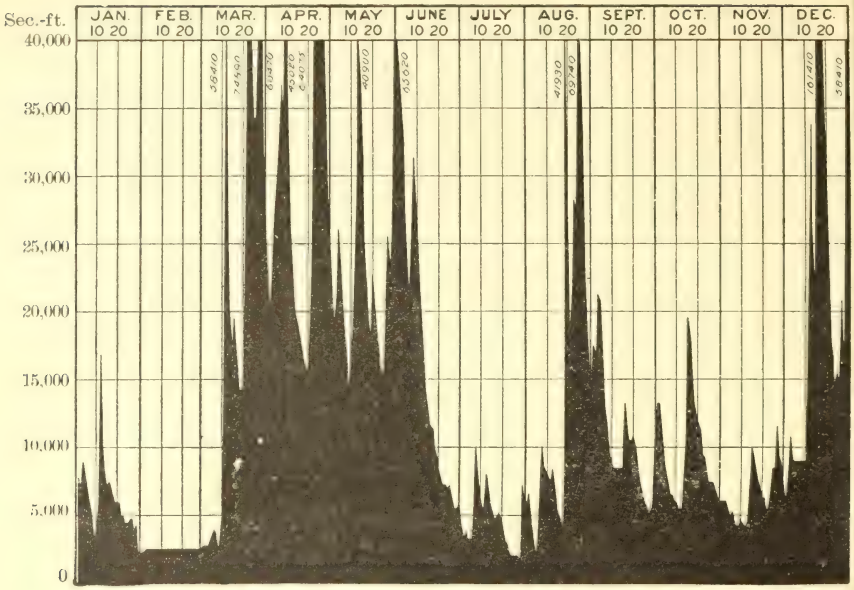


FIG. 8.—Discharge of Delaware River at Lambertville, N. J.

Estimated monthly discharge of Tohickon River at Point Pleasant, Pa.

[Drainage area, 102 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,768	12	145	1.42	1.64
February	11	4	9	.09	.09
March	3,353	9	461	4.52	5.11
April	2,388	31	372	3.63	4.05
May	1,219	7	202	1.98	2.28
June	289	3	58	.57	.64
July	7	3	5	.05	.06
August	893	4	123	1.21	1.40
September	608	7	40	.39	.44
October	52	5	17	.17	.20
November	201	4	27	.26	.29
December	4,039	19	622	6.10	7.02
The year	4,039	3	173	1.70	23.22

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 215.

Estimated monthly discharge of Neshaminy Creek, Pennsylvania, below the forks.

[Drainage area, 139 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,965	31	151	1.09	1.26
February	72	41	46	.33	.34
March	4,624	51	421	3.03	3.48
April	1,774	92	434	3.12	3.49
May	1,029	88	253	1.82	2.10
June	509	41	111	.80	.89
July	1,320	31	179	1.29	1.48
August	2,385	63	331	2.38	2.75
September	1,676	45	196	1.41	1.57
October	73	22	39	.28	.32
November	1,173	18	78	.56	.62
December	3,829	48	549	3.95	4.55
The year	4,624	18	232	1.67	22.85

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 216.

Estimated monthly discharge of Perkiomen Creek at Frederick, Pa.

[Drainage area, 152 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,623	31	139	0.91	1.05
February	84	29	44	.29	.30
March	4,717	46	441	2.91	3.35
April	2,237	58	337	2.22	2.48
May	1,113	67	236	1.55	1.79
June	547	36	119	.78	.87
July	137	12	44	.29	.33
August	1,433	36	184	1.21	1.40
September	250	38	87	.57	.64
October	260	31	80	.33	.61
November	368	36	72	.47	.52
December	6,017	51	557	3.67	4.22
The year	6,017	12	195	1.27	17.56

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 217.

Estimated monthly discharge of Wissahickon Creek, near Philadelphia, Pa.

[Drainage area, 65 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	240	12	54	0.83	0.96
February	64	16	38	.58	.60
March 1–9	24	17	18	.28	.09
August	1,095	19	138	2.12	2.45
September	99	20	32	.49	.55
October	48	16	30	.46	.53
November	515	13	37	.57	.64
December	1,269	17	133	2.05	2.37

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 65, page 218.

SUSQUEHANNA RIVER AND TRIBUTARIES.

During 1901 measurements have been made of Susquehanna River and its principal tributaries, as follows: North Branch of Susquehanna River at Wilkesbarre, Pa., and at Danville, Pa.; West Branch of Susquehanna River at Williamsport, Pa., and at Allenwood, Pa.; Juniata River at Newport, Pa., and Susquehanna River at Harrisburg, Pa. Owing to lack of sufficient discharge measurements the monthly figures of flow for the Williamsport, Wilkesbarre, and Allenwood stations were not computed for 1901. Results for the other stations are given in the following tables, the figures of discharge for the Susquehanna at Harrisburg including the flow of the Pennsylvania Canal at that point:

Estimated monthly dischage of North Branch of Susquehanna River at Danville, Pa.

[Drainage area, 11,070 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January			[a]30,000	2.71	3.12
February			[a]30,000	2.71	2.82
March			[a]52,136	4.71	5.43
April	88,640	22,400	38,120	3.44	3.84

Estimated monthly discharge of North Branch of Susquehanna River at Danville, Pa.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May	83,600	14,310	25,209	2.28	2.63
June	74,960	6,800	20,223	1.83	2.04
July	6,400	2,500	4,079	.37	.43
August	56,240	2,750	12,646	1.14	1.31
September	13,135	3,300	6,042	.55	.61
October	8,100	3,600	5,535	.50	.58
November	27,440	2,750	6,412	.58	.65
December	139,760	7,200	35,246	3.18	3.67
The year	139,760	2,500	22,121	2.00	27.13

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 220; rating table on page 318 of same paper.

Estimated monthly discharge of Juniata River at Newport, Pa.

[Drainage area, 3,476 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,500	1,200	2,224	0.64	0.74
February	4,000	1,600	2,634	.76	.79
March	59,500	2,040	12,155	3.50	4.04
April	49,000	5,850	16,957	4.88	5.45
May	46,500	3,250	13,187	3.79	4.37
June	24,000	3,250	6,792	1.95	2.18
July	6,900	1,600	2,845	.82	.95
August	11,150	1,200	3,880	1.12	1.29
September	7,700	1,400	3,134	.90	1.00
October	2,270	1,000	1,447	.42	.48
November	5,850	1,000	1,637	.47	.52
December	70,000	2,040	13,731	3.95	4.55
The year	70,000	1,000	6,719	1.93	26.36

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 226; rating table on page 318 of same paper.

Estimated monthly discharge of Susquehanna River at Harrisburg, Pa.

[Drainage area, 24,030 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	27,925	7,830	14,498	0.60	0.69
February	35,400	11,900	20,236	.84	.87
March	193,160	11,125	82,431	3.43	3.96
April	205,690	47,275	105,569	4.39	4.90
May	211,060	27,925	63,966	2.66	3.07
June	187,790	24,500	55,296	2.30	2.56
July	24,500	10,100	14,012	.58	.67
August	123,350	8,475	33,663	1.40	1.61
September	54,435	11,125	22,262	.93	1.04
October	19,800	9,450	13,669	.57	.66
November	58,910	6,880	15,265	.64	.71
December	347,100	15,100	70,990	2.95	3.41
The year	347,100	6,880	42,655	1.77	24.15

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 227; rating table on page 318 of same paper.

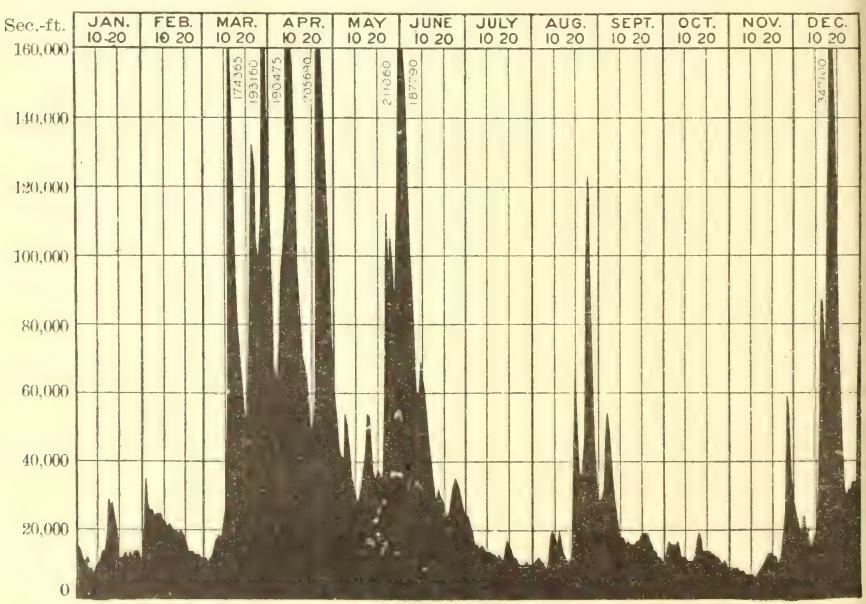


FIG. 9.—Discharge of Susquehanna River at Harrisburg, Pa., 1901.

PATAPSCO RIVER.

The river rises in the north central part of Maryland and empties into Chesapeake Bay about 13 miles below Baltimore. Its watershed is a hilly country, largely under cultivation. The station at Woodstock, Md., was established August 6, 1896, since which time continuous records have been kept, which have been published in former annual reports. The record for 1901 is given herewith.

Estimated monthly discharge of Patapsco River at Woodstock, Md.

[Drainage area, 251 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	670	122	207	0.82	0.95
February	310	186	239	.95	.99
March	5,075	252	792	3.16	3.64
April	2,102	160	508	2.02	2.25
May	1,600	160	380	1.51	1.74
June	1,100	91	276	1.10	1.23
July	1,600	100	245	.98	1.13
August	5,280	66	366	1.46	1.68
September[a]					
October	590	111	209	.83	.96
November	2,000	91	239	.95	1.06
December	8,048	310	1,014	4.04	4.66

[a] No record.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 228; rating table on page 318 of same paper.

POTOMAC RIVER AND TRIBUTARIES.

Potomac River is formed by the junction of the North and South branches, about 15 miles below Cumberland, Md. Regular gaging stations have been maintained on the North Branch at Piedmont, W. Va., on the South Branch near Springfield, W. Va., on Antietam Creek near Sharpsburg, Md., on the North Branch of Shenandoah River near Riverton, Va., on the South Branch of Shenandoah River near Front Royal, Va., on Shenandoah River at Millville, W. Va., on Potomac River at Point of Rocks, Md., and on Monocacy River near Frederick, Md. During a flood in the early part of 1902 the bridge and the gage near Springfield were carried away and the sta-

tion was abandoned. It was established June 26, 1899, and the results of the measurements for the entire period are published below.

Estimated monthly discharge of North Branch of Potomac River at Piedmont, W. Va.

[Drainage area, 407 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,360	336	682	1.68	1.94
February	705	305	403	.99	1.03
March	3,480	305	1,258	3.09	3.56
April	4,280	672	1,810	4.45	4.97
May	4,200	475	1,422	3.49	4.02
June	1,720	390	937	2.30	2.57
July	3,400	175	482	1.18	1.36
August	1,800	149	423	1.04	1.20
September	430	124	224	.55	.61
October	230	100	130	.32	.37
November	352	77	137	.34	.38
December	5,240	202	1,271	3.12	3.60
The year	5,240	77	765	1.88	25.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 229; rating table on page 318 of same paper.

Estimated monthly discharge of South Branch of Potomac River near Springfield, W. Va.

[Drainage area, 1,440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	730	240	358	0.25	0.29
August	400	250	286	.20	.23
September	400	250	333	.23	.26
October	890	250	332	.23	.27
November	2,240	400	1,134	.79	.88
December	2,150	335	1,051	.73	.84

Estimated monthly discharge of South Branch of Potomac River near Springfield, W. Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile	Depth in inches.
1900.					
January	4,335	500	1,154	.80	.92
February	3,750	1,500	2,576	1.79	1.86
March	5,415	1,070	3,129	2.17	2.51
April	3,600	285	1,486	1.03	1.15
May	896	265	507	.35	.40
June	6,135	540	1,728	1.20	1.34
July	1,790	250	856	.59	.68
August	730	230	331	.23	.27
September	980	230	347	.24	.27
October	600	285	367	.26	.30
November	5,685	265	1,085	.75	.84
December	5,685	335	1,307	.91	1.05
The year	6,135	230	1,239	.86	11.59
1901.					
January	4,425	335	1,151	0.80	0.92
February	600	500	518	.36	.38
March	7,575	490	2,216	1.54	1.78
April	10,185	730	3,777	2.62	2.92
May	8,295	980	2,910	2.02	2.33
June	7,035	890	2,441	1.70	1.90
July	3,050	250	1,316	.91	1.05
August	980	265	498	.35	.40
September	4,380	285	774	.54	.60
October	1,070	265	357	.25	.29
November	1,610	250	375	.26	.29
December	9,735	335	2,611	1.81	2.09
The year	10,185	250	1,579	1.10	14.95

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 229; rating table on page 318 of same paper.

Estimated monthly discharge of Antietam Creek near Sharpsburg, Md.

[Drainage area, 293 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	123	60	76	0.26	0.30
February	154	48	79	.27	.28
March	2,241	60	293	1.00	1.15
April	2,127	416	649	2.22	2.48
May	2,543	249	532	1.82	2.10
June	485	281	359	1.23	1.37
July	382	154	255	.87	1.00
August	1,058	123	225	.77	.89
September	416	95	171	.58	.65
October	281	75	123	.42	.48
November 1–16			83	.28	.31

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 230; rating table on page 318 of same paper.

Estimated monthly discharge of North Branch of Shenandoah River near Riverton, Va.

[Drainage area, 1,034 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	2,645	215	676	0.65	0.75
February	380	240	288	.28	.29
March	11,270	190	1,378	1.33	1.53
April	15,870	747	3,622	3.50	3.90
May	13,915	920	2,578	2.49	2.87
June	10,925	1,265	2,787	2.70	3.01
July	4,945	530	1,597	1.54	1.78
August	3,450	430	960	.93	1.07
September	2,760	165	740	.72	.80
October	1,610	190	406	.39	.45
November	2,070	140	376	.36	.40
December	14,145	270	2,911	2.82	3.25
The year	15,870	140	1,527	1.48	20.10

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 231; rating table on page 319 of same paper.

Estimated monthly discharge of South Branch of Shenandoah River near Front Royal, Va.

[Drainage area, 1,569 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	915	385	493	0.31	0.36
August	1,250	315	556	.35	.40
September	2,050	440	717	.46	.51
October	640	410	514	.33	.38
November	6,070	605	1,205	.77	.86
December	4,090	470	1,093	.70	.81
1900.					
January	10,840	915	2,186	1.39	1.60
February	7,600	915	2,400	1.53	1.59
March	10,750	1,640	3,482	2.22	2.56
April	3,640	1,100	1,744	1.11	1.24
May	1,975	675	1,127	.72	.83
June	5,890	605	1,703	1.09	1.22
July	1,100	470	736	.46	.53
August	750	360	493	.31	.36
September	1,052	315	457	.29	.32
October	4,090	502	1,020	.65	.75
November	6,790	535	1,255	.80	.89
December	5,260	675	1,394	.89	1.03
The year	10,840	315	1,500	.96	12.92

Estimated monthly discharge of South Branch of Shenandoah River near Front Royal, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,260	470	1,353	0.87	1.00
February	1,200	535	779	.50	.52
March	11,020	470	1,909	1.22	1.41
April	27,580	1,580	6,611	4.21	4.69
May	23,980	1,640	4,920	3.14	3.62
June	11,380	1,900	4,279	2.73	3.04
July	13,180	1,410	3,834	2.44	2.82
August	6,340	1,052	3,259	2.08	2.40
September	7,600	675	1,807	1.15	1.28
October	9,220	712	1,772	1.13	1.30
November	2,920	605	930	.59	.66
December	27,580	1,200	4,658	2.97	3.43
The year	27,580	470	3,009	1.92	26.17

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 232; rating table on page 319 of same paper.

Estimated monthly discharge of Shenandoah River at Millville, W. Va.

[Drainage area, 2,995 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean	Second-feet per square mile.	Depth in inches.
1901.					
January	5,790	840	1,828	0.61	0.70
February	1,950	740	1,272	.42	.44
March	17,840	840	3,302	1.10	1.27
April	29,520	2,515	10,612	3.54	3.95
May	29,840	2,600	7,674	2.56	2.96
June	26,640	3,740	7,592	2.54	2.83
July	12,880	1,310	4,344	1.45	1.67
August	2,780	1,725	3,480	1.16	1.34
September	11,280	1,250	2,487	.83	.93
October	6,320	1,140	1,784	.60	.69
November	3,950	940	1,366	.46	.51
December	30,160	1,370	6,421	2.14	2.47
The year	30,160	740	4,347	1.45	19.76

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 233; rating table on page 319 of same paper.

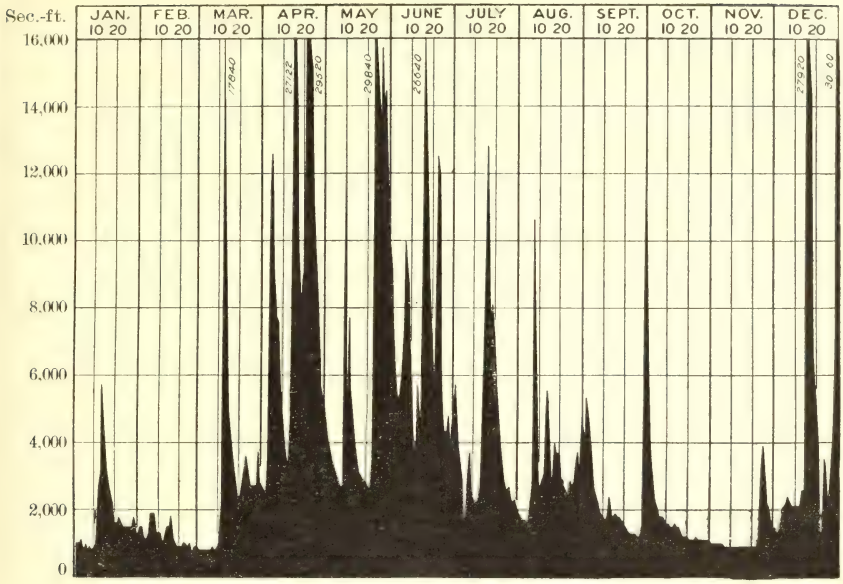


FIG. 10.—Discharge of Shenandoah River at Millville, W. Va., 1901.

Estimated monthly discharge of Potomac River at Point of Rocks, Md.

[Drainage area, 9,654 square miles]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,560	1,860	4,923	0.51	0.59
February	6,020	2,360	3,578	.37	.39
March	86,610	2,360	13,976	1.45	1.67
April	172,150	7,000	40,829	4.23	4.72
May	111,180	6,020	28,747	2.98	3.44
June	49,300	7,980	19,398	2.00	2.23
July	27,050	4,700	10,715	1.11	1.28
August	20,950	3,950	8,256	.86	.99
September	28,270	3,600	7,539	.78	.87
October	11,900	2,630	4,206	.44	.51
November	20,340	2,380	4,681	.48	.54
December	139,390	4,300	26,426	2.74	3.16
The year	172,150	1,860	14,440	1.50	20.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 233; rating table on page 319 of same paper.

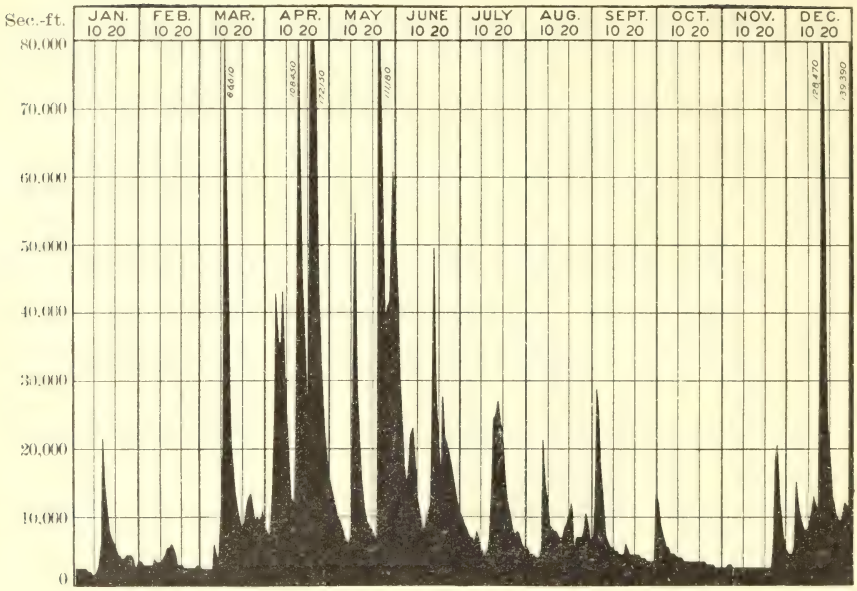


FIG. 11.—Discharge of Potomac River at Point of Rocks, Md., 1901.

Estimated monthly discharge of Monocacy River near Frederick, Md.

[Drainage area, 665 square miles].

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,170	150	461	0.69	0.80
February	550	240	347	.52	.54
March	15,984	270	2,085	3.14	3.62
April	14,264	700	2,650	3.98	4.44
May	5,750	420	1,521	2.29	2.64
June	2,740	305	875	1.32	1.47
July	750	180	332	.50	.58
August	1,966	150	464	.70	.81
September	1,622	180	311	.47	.52
October	600	180	283	.43	.50
November	3,944	210	495	.74	.83
December	14,264	380	2,193	3.30	3.81
The year	15,984	150	1,001	1.51	20.56

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 234; rating table on page 319 of same paper.

JAMES RIVER AND TRIBUTARIES.

Records of measurements have been kept as in previous years on North (of James) River at Glasgow, Va.; on James River at Buchanan, Va., Holcomb Rock, Va., and at Cartersville, Va. A station was established on Appomattox River at Mattoax, Va., on August 26, 1900, and was maintained during 1901. The results of measurements at this station for the entire period are given below. No results are here given for the station at Holcomb Rock, as no discharge measurements are made at that place.

Estimated monthly discharge of North (of James) River at Glasgow, Va.

[Drainage area, 831 square miles.]

Month.	Discharge in second-feet.			Run-off	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,602	280	751	0.90	1.04
February	400	280	339	.41	.43
March	7,050	280	1,757	2.11	2.44
April	12,170	720	3,124	3.76	4.20
May	12,170	650	1,996	2.40	2.77
June	14,015	685	2,246	2.69	3.00
July	2,100	400	847	1.02	1.18
August	7,050	330	1,793	2.16	2.49
September	3,008	450	724	.87	.97
October	845	280	395	.48	.55
November	450	250	289	.35	.39
December	24,060	280	3,240	3.90	4.50
The year	24,060	250	1,418	1.75	23.96

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 235; rating table on page 319 of same paper.

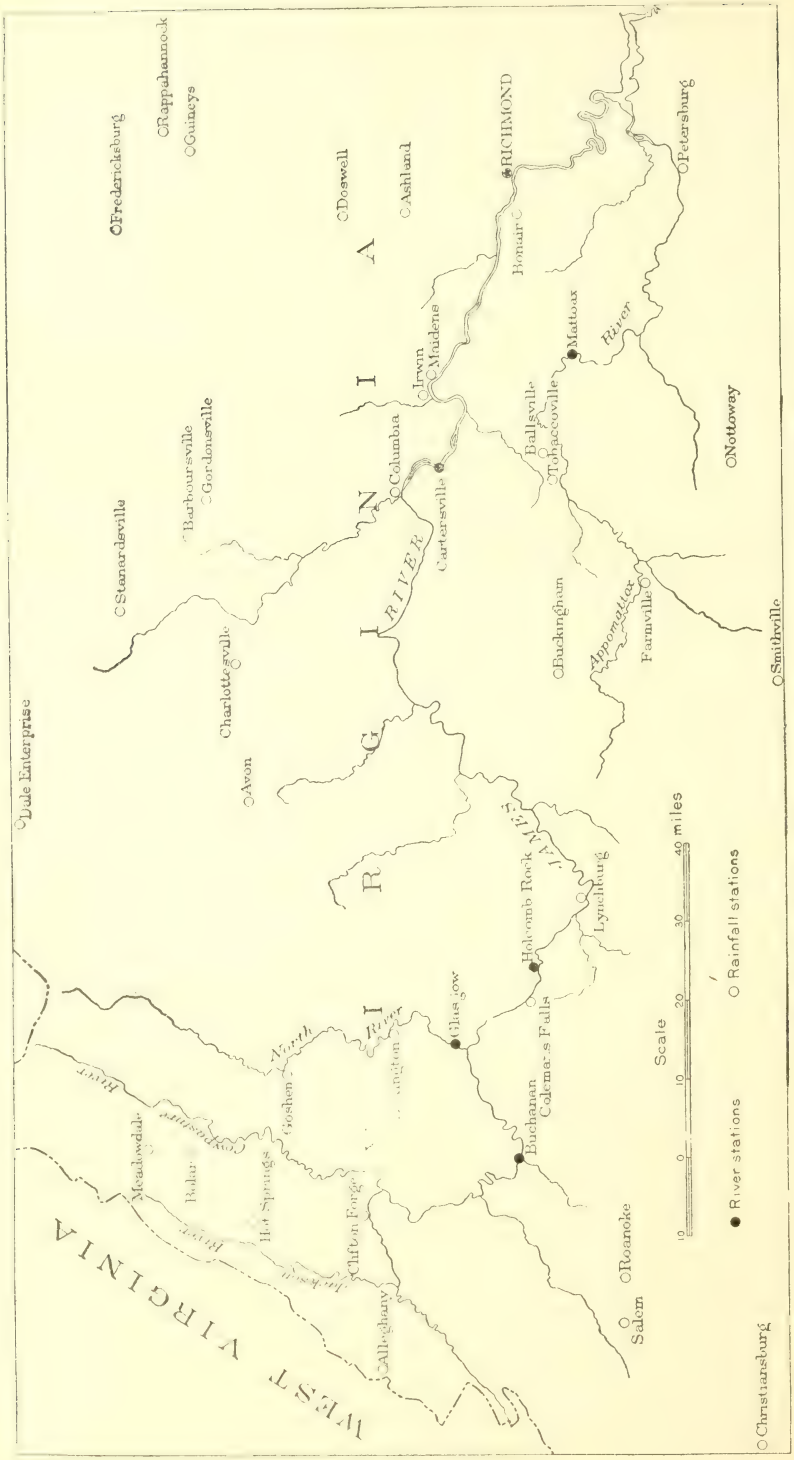


FIG. 12.—Location of river and rainfall stations in basin of James River.

Estimated monthly discharge of James River at Buchanan, Va.

[Drainage area, 2,058 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	18,956	750	2,739	1.33	1.53
February	1,980	750	1,234	.60	.62
March	16,580	750	3,786	1.84	2.12
April	25,820	2,870	8,589	4.17	4.65
May	31,620	1,650	5,882	2.86	3.30
June	25,028	1,980	5,609	2.72	3.03
July	6,185	840	2,594	1.26	1.45
August	20,276	750	4,683	2.27	2.62
September	9,980	670	1,605	.78	.87
October	1,650	540	726	.35	.40
November	840	430	518	.25	.28
December	48,260	540	6,736	3.27	3.77
The year	48,260	430	3,725	1.81	24.64

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 236; rating table on page 319 of same paper.

Estimated monthly discharge of James River at Cartersville, Va.

[Drainage area, 6,232 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,880	2,755	9,220	1.48	1.71
February	4,666	2,668	3,648	.59	.61
March	29,600	2,411	8,217	1.32	1.52
April	62,765	6,765	24,509	3.93	4.38
May	75,800	5,300	17,762	2.85	3.29
June	53,360	7,240	17,172	2.76	3.08
July	17,390	3,021	7,750	1.24	1.43
August	47,090	2,496	16,668	2.67	3.08
September	26,300	3,294	6,836	1.10	1.23
October	12,200	2,327	3,725	.60	.69
November	9,390	2,078	2,816	.45	.50
December	75,470	2,582	15,926	2.56	2.95
The year	75,800	2,078	11,187	1.80	24.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 238; rating table on page 319 of same paper.

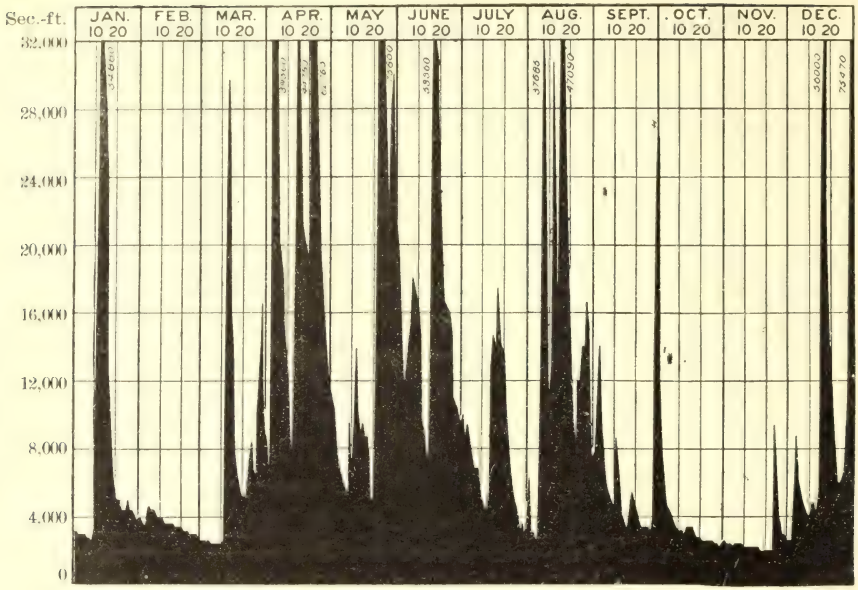


FIG. 13.—Discharge of James River at Cartersville, Va., 1901.

Estimated monthly discharge of Appomattox River at Mattoax, Va.

[Drainage area, 745 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	663	78	171	0.23	0.26
October	277	153	183	.24	.28
November	487	171	232	.31	.35
December	1,600	165	383	.51	.59
1901.					
January	5,560	243	986	1.32	1.52
February	580	249	339	.45	.47
March	2,755	243	517	.69	.80
April	8,050	378	2,433	3.26	3.64
May	12,050	279	2,084	2.79	3.22
June	825	243	427	.57	.64
July	2,160	195	524	.70	.81
August	6,550	165	2,664	3.57	4.12
September	1,680	261	446	.60	.67
October	1,280	249	333	.45	.52
November	1,120	249	314	.42	.47
December	5,950	285	1,456	1.96	2.26
The year	12,050	165	1,043	1.40	19.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, on page 238; rating table on page 319 of same paper.

PRECIPITATION IN THE BASIN OF JAMES RIVER.

The principal observations of rainfall made within the James River Basin are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of the points is shown in fig. 12, in connection with the points of river measurement, which are located at Buchanan, Glasgow, Holcomb Rock, Cartersville, and Mattoax.

Location of rainfall stations in James River Basin.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Ashland	Hanover	Virginia	37 45	77 30	220	9–10
Barboursville	Orange	do			500	5–6
Bedford City	Bedford	do			900	10–12
Bonair	Chesterfield	do			325	7–8
Buckingham	Buckingham	do			550	5–8
Christiansburg	Montgomery	do	37 5	80 23	2,760	12–15
Clifton Forge	Alleghany	do	37 50	79 55	1,047	4–6
Dale Enterprise	Rockingham	do	38 40	78 45	850	22
Doswell	Hanover	do			134	4–5
Farmville	Prince Edward	do			316	3–5
Fredericksburg	Spottsylvania	do			47	7–9
Hot Springs	Bath	do			2,195	7–10
Lexington	Rockbridge	do			946	25–31
Lynchburg	Campbell	do	37 25	79 9	681	29–31
Petersburg	Dinwiddie	do	37 12	77 20	11	14–16
Richmond	Henrico	do	37 32	77 26	172	22–24
Salem	Roanoke	do				11–12
Stanardsville	Greene	do			1,150	10–11
Staunton	Augusta	do	38 9	79 4	1,340	13–16

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896 to 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of James River.

ASHLAND, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.93	3.33	3.41	3.78	4.90	3.36	5.25	3.53	3.65	3.70	2.57	2.45	42.86
1896	2.35	3.56	4.12	2.00	3.37	3.67	6.64	1.46	5.49	.56	2.42	.51	36.15
1897	1.52	6.26	4.56	2.82	3.01	3.64	4.93	2.23	.80	6.93	3.47	2.67	42.89
1898	1.61	.78	4.18	5.09	6.05	3.94	4.42	4.82	2.86	4.33	1.93	3.33	43.34
1899	3.84	4.60	5.82	1.11	3.14	2.38	6.76	5.11	4.48	3.98	1.57	2.42	45.21
1900	3.29	5.09	2.62	3.42	2.59	5.25	1.62	1.21	3.47	3.63	2.43	2.83	37.45
1901	3.11	.36	3.82	5.66	6.46	1.40	6.82	10.13	3.89	1.40	1.40	5.40	49.85

Precipitation at stations in drainage basin of James River—Continued.

BARBOURSVILLE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.04	3.36	3.45	3.40	5.58	4.10	4.43	3.98	3.86	2.23	2.52	3.66	43.61
1896	(3.04)	(3.36)	(3.45)	(3.40)	(5.58)	(4.10)	(4.43)	(3.98)	6.40	.28	4.02	.06	42.10
1897	1.76	5.56	2.71	2.06	6.04	3.63	4.50	1.08	.80	4.56	2.16	3.92	38.78
1898	2.80	.72	4.68	3.19	7.66	3.97	4.69	(3.98)	(3.86)	(2.23)	(2.52)	(3.66)	43.96
1899	3.76	5.65	(3.45)	1.81	2.50	2.80	5.46	3.14	4.90	3.50	1.55	3.01	41.53
1900	4.17	4.45	3.60	2.50	1.41	5.63	1.60	2.72	4.34	2.35	2.48	2.80	38.05
1901	2.73	.42	2.80	7.46	10.28	4.46	5.89	9.00	2.87	.47	2.37	8.51	57.26

BEDFORD CITY, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.89	3.54	3.21	3.13	4.21	3.58	3.75	4.76	3.69	3.31	2.33	3.29	41.69
1896	2.16	4.30	5.13	1.89	1.82	(3.58)	(3.75)	3.55	6.75	(3.31)	5.00	(3.29)	44.53
1897	(2.89)	(3.54)	3.10	1.50	3.70	3.68	1.70	.87	1.00	3.63	2.52	3.55	31.68
1898	2.48	1.02	4.03	3.21	7.81	2.53	4.26	3.67	4.08	8.66	2.05	4.16	47.96
1899	3.96	(3.54)	(3.21)	(3.13)	(4.21)	5.76	5.22	6.86	4.27	2.18	.69	1.82	44.85
1900	4.39	5.57	1.56	3.93	2.92	4.67	3.65	1.31	5.30	2.93	1.87	4.25	42.35
1901	2.68	.90	3.72	6.13	4.99	4.24	5.07	15.17	2.73	.43	1.34	8.10	55.50

BONAIR, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.19	3.39	4.31	4.13	3.93	3.09	5.03	3.71	3.61	3.44	2.73	3.17	43.73
1896	2.98	4.21	3.98	2.22	4.21	6.11	7.13	1.26	4.61	.89	3.27	1.27	41.94
1897	1.90	6.27	5.00	2.62	2.46	2.11	3.74	1.73	.86	6.52	4.37	4.01	41.69
1898	1.72	.81	3.43	4.71	6.95	2.34	3.50	4.74	3.22	4.89	2.93	3.25	42.49
1899	4.23	5.85	6.28	1.48	2.16	2.83	4.24	5.34	5.55	3.43	.86	1.95	44.20
1900	2.54	4.10	2.58	4.37	2.47	3.57	2.49	1.15	3.64	3.97	2.99	3.00	36.87
1901	3.79	.69	4.28	5.63	4.19	2.61	8.86	9.66	3.31	.99	7.71	6.94	52.66

BUCKINGHAM, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.32	3.46	3.94	3.24	4.19	2.83	3.81	4.76	4.14	3.13	2.24	2.89	41.95
1896	3.30	3.74	(3.94)	2.02	4.96	4.41	6.08	2.27	4.83	.29	3.79	T.	39.63
1897	.92	6.70	3.56	2.95	3.02	1.90	2.92	.73	1.05	4.72	3.47	2.77	34.71
1898	2.00	.40	2.23	3.20	3.53	1.75	5.00	3.90	2.08	6.60	2.17	3.56	36.42
1899	4.53	5.61	8.05	1.94	4.36	3.29	2.97	7.46	4.76	3.35	.88	1.70	40.90
1900	3.62	5.42	3.45	2.92	2.65	5.62	3.21	2.22	2.66	2.10	3.46	3.03	40.36
1901	3.49	.59	2.40	6.40	[a]6.47	2.46	2.49	13.75	6.02	.46	.30	7.43	[a]52.26

CHRISTIANSBURG, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.63	3.08	3.55	2.36	4.30	3.63	3.60	3.53	3.59	3.12	1.95	2.13	37.47
1896	1.07	2.64	6.36	2.80	3.91	3.76	6.94	1.21	5.20	1.15	3.72	.60	39.36
1897	1.59	6.80	3.62	1.76	2.88	2.04	4.34	3.23	2.13	3.88	.81	3.66	36.74
1898	2.78	.30	3.08	1.93	5.86	2.52	4.21	3.13	4.17	5.11	2.28	2.54	38.00
1899	4.07	4.97	7.11	3.36	3.39	4.52	2.64	2.92	4.01	1.11	2.42	2.08	42.60
1900	2.09	3.53	5.37	2.24	4.34	8.87	1.37	2.38	5.67	3.85	3.10	3.20	46.01

CLIFTON FORGE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.08	3.05	3.49	2.69	4.51	3.17	2.78	3.05	3.15	2.97	2.69	1.65	35.28
1896	(2.08)	(3.05)	(3.49)	(2.69)	(4.51)	(3.17)	(2.78)	(3.05)	6.43	.28	5.56	T.	37.09
1897	2.35	5.19	3.35	1.13	4.46	3.83	3.78	4.32	.46	2.87	2.64	3.54	37.92
1898	2.66	.51	3.24	2.58	4.13	1.28	3.69	2.78	3.65	7.92	(2.69)	2.33	37.46
1899	1.49	4.29	3.70	(2.69)	(4.51)	1.65	1.42	2.12	.31	.89	.38	1.23	24.68
1900	1.78	4.92	2.67	2.10	3.80	4.23	2.25	.77	5.02	5.46	4.11	.80	37.91
1901	2.12	.35	4.50	4.96	5.65	4.85	(2.78)	5.24	3.02	.40	.76	2.00	36.63

[a] Incomplete.

Precipitation at stations in drainage basin of James River—Continued.

DALE ENTERPRISE, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	2.68	3.19	3.26	3.17	4.87	5.36	4.31	3.89	3.95	2.92	2.39	2.63	42.62
1896	1.75	3.40	3.70	1.19	1.99	5.17	5.69	1.55	7.85	.16	4.30	.....	34.73
1897	1.56	5.64	2.40	1.70	5.37	2.88	4.15	.68	.43	2.55	2.40	3.23	32.99
1898	2.37	.61	3.90	2.91	4.94	4.83	6.24	9.54	2.23	7.39	1.82	3.60	50.38
1899	1.87	5.57	4.34	1.21	3.75	1.86	3.15	2.18	4.40	1.75	.91	1.00	31.99
1900	3.20	2.87	3.38	1.70	2.06	8.01	3.47	2.44	3.22	2.45	3.11	1.61	37.52
1901	2.04	.28	3.86	5.78	5.11	14.37	4.83	6.36	3.84	2.06	1.39	6.37	56.29

DOSWELL, VA.

Normal	2.93	2.20	3.37	3.15	3.21	2.46	3.35	4.14	2.68	2.97	3.02	1.98	35.46
1897	3.15	(2.20)	4.10	1.90	2.70	2.38	2.09	2.40	.70	5.60	2.57	2.80	32.59
1898	1.60	.79	4.35	5.23	3.82	2.26	5.23	(4.14)	2.80	(2.97)	3.47	1.16	37.82
1899	4.26	4.68	4.90	.96	2.45	2.22	2.45	(4.14)	4.50	2.02	(3.02)	(1.98)	37.58
1900	(2.93)	3.32	1.50	2.89	2.40	2.28	2.01	.92	1.58	2.73	(3.02)	(1.98)	27.56
1901	2.72	.02	1.98	4.78	4.68	3.14	4.99	9.11	3.82	1.51	(3.02)	(1.98)	41.75

FARMVILLE, VA.

Normal	2.38	4.24	4.59	3.25	4.88	4.33	4.77	3.16	2.41	2.65	1.78	2.51	40.95
1897	(2.38)	(4.24)	4.20	1.01	3.65	3.85	6.93	.33	T.	4.83	1.50	1.91	34.83
1898	.65	(4.24)	3.09	4.23	5.49	2.80	6.63	3.67	3.01	4.81	2.25	3.35	44.22
1899	3.55	6.14	9.72	1.82	2.84	4.61	2.50	8.02	2.98	2.01	1.95	1.02	47.16
1900	(2.38)	5.15	2.87	3.30	2.48	8.19	3.58	1.82	2.68	1.48	1.82	4.00	39.75
1901	2.95	1.45	3.10	6.00	9.97	2.20	4.20	1.95	3.40	.10	1.40	[a]2.30	[a]39.02

FREDERICKSBURG, VA.

Normal	2.63	3.82	3.47	3.54	4.67	3.62	4.06	3.37	2.95	3.42	2.18	2.93	40.66
1896	1.54	3.65	3.85	1.90	4.60	5.41	5.50	1.28	4.93	.14	2.60	.08	35.48
1897	1.70	6.40	3.02	2.31	4.59	3.63	5.04	2.04	.68	5.25	1.99	3.17	39.82
1898	3.17	1.19	4.55	4.28	7.47	2.02	3.10	4.44	1.19	5.39	2.07	4.01	42.88
1899	4.61	6.79	5.41	1.50	5.18	3.40	3.39	4.45	5.36	4.38	1.59	1.82	47.88
1900	3.16	4.73	3.00	3.83	1.17	7.09	2.81	.96	4.36	5.32	2.09	3.43	41.95
1901	3.09	.50	3.02	6.34	3.89	2.56	5.33	8.23	2.48	.46	1.58	7.90	45.38

HOT SPRINGS, VA.

Normal	2.42	3.87	3.21	2.83	4.36	4.16	3.89	3.39	3.35	3.27	2.11	3.11	39.97
1896	(2.42)	3.68	5.80	.94	3.63	3.79	4.47	4.16	6.42	.47	5.16	.19	41.13
1897	2.15	6.96	2.89	1.21	5.73	3.52	3.26	1.08	.63	2.11	2.02	3.98	35.54
1898	1.99	.79	4.10	(2.83)	(4.36)	(4.16)	5.11	8.00	3.90	11.80	(2.11)	2.73	51.88
1899	2.84	8.18	5.91	1.58	2.34	3.78	6.72	3.45	.36	5.24	.50	1.23	42.13
1900	2.31	5.86	2.84	1.79	3.50	4.46	5.25	1.79	4.91	4.33	(2.11)	2.70	41.85
1901	2.33	.23	3.91	8.26	7.74	6.22	3.79	6.22	4.20	.70	2.35	9.50	55.45

LEXINGTON, VA.

Normal	3.35	3.27	3.39	3.03	3.79	3.62	3.98	3.73	4.03	2.85	2.90	2.75	40.69
1896	2.93	4.21	4.97	1.11	1.55	4.31	8.10	5.65	5.88	.31	5.35	.15	44.52
1897	1.76	5.79	3.44	1.58	4.63	3.33	3.99	3.03	1.09	2.56	2.44	3.42	37.06
1898	2.58	.77	3.47	2.59	5.81	4.72	4.44	6.24	3.61	7.83	2.10	2.90	47.06
1899	3.79	5.41	6.69	1.25	5.00	2.62	3.18	5.41	4.01	2.08	.50	1.47	41.41
1900	2.92	4.38	4.03	2.73	2.70	7.49	3.12	1.12	3.79	3.08	2.73	2.21	40.30
1901	3.00	.57	3.97	5.40	4.61	(3.62)	(3.98)	(3.73)	(4.03)	(2.05)	1.32	8.12	44.40

[a] Incomplete.

Precipitation at stations in drainage basin of James River—Continued.

LYNCHBURG, VA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct	Nov.	Dec.	Annual.
Normal	3.89	3.63	3.91	3.28	4.16	3.62	4.20	4.13	3.89	3.25	2.88	3.15	43.99
1896	2.30	4.54	5.54	1.61	5.01	3.82	8.58	2.04	7.08	1.07	4.92	.13	46.64
1897	2.19	7.84	3.46	2.08	4.27	2.70	6.75	.94	1.12	3.12	2.24	3.37	40.08
1898	2.16	.74	3.25	2.94	9.08	2.98	7.17	2.82	4.50	7.33	2.61	4.35	49.93
1899	4.95	5.86	9.01	1.52	2.99	4.84	3.87	7.50	4.54	3.87	2.22	1.74	52.91
1900	4.36	4.38	4.35	3.74	4.07	8.31	1.92	2.29	4.78	3.49	2.31	3.10	47.10
1901	3.59	.78	3.66	5.98	5.34	4.93	4.33	12.36	3.17	.48	1.47	8.72	54.81

PETERSBURG, VA.

Normal	2.62	3.61	4.55	3.79	5.22	3.73	4.84	3.73	4.13	3.44	2.80	2.56	45.02
1896	2.58	4.64	3.33	1.91	7.25	5.90	8.33	.70	3.05	.63	2.53	1.93	42.78
1897	1.96	5.85	5.71	2.52	3.40	2.19	2.72	1.20	1.69	4.88	2.78	2.66	37.56
1898	1.21	.78	3.95	4.90	5.35	2.57	4.74	2.83	2.31	3.33	2.43	2.04	36.44
1899	2.94	5.57	5.93	1.73	4.16	3.07	6.13	5.81	4.09	3.05	1.26	1.97	45.71
1900	2.95	4.54	2.74	2.50	1.69	6.49	4.14	2.42	3.67	2.82	4.87	2.88	41.71
1901	2.68	.70	3.99	5.00	5.12	2.81	3.64	7.13	3.45	2.71	2.48	6.15	45.86

RICHMOND, VA.

Normal	3.08	3.64	3.81	3.71	3.90	3.32	4.62	5.15	4.16	3.41	2.53	3.40	44.73
1898	1.05	1.05	3.78	4.83	5.28	2.98	4.15	6.31	2.38	4.59	2.22	3.08	41.65
1899	2.94	4.72	5.56	2.04	2.14	2.41	4.12	5.61	6.21	4.03	1.19	2.33	43.30
1900	2.71	4.42	2.89	3.62	2.20	3.08	3.13	3.66	4.03	2.55	2.87	2.60	37.76
1901	2.80	.55	3.79	5.29	3.80	2.32	5.06	6.99	3.21	.79	1.37	6.08	42.05

SALEM, VA.

Normal	2.94	3.88	3.75	2.98	4.34	3.67	4.09	4.59	3.87	3.07	1.94	2.96	42.08
1896	2.82	4.37	5.77	2.46	2.01	4.79	6.53	1.41	4.92	.53	5.16	.41	41.18
1897	1.69	7.56	3.73	1.56	4.03	1.31	3.64	1.76	2.56	4.17	1.25	3.82	37.08
1898	2.95	.58	3.35	1.99	6.74	2.82	5.06	4.14	3.66	8.63	1.50	2.58	44.00
1899	3.37	6.09	5.87	2.59	2.35	3.27	3.46	4.44	4.44	2.08	1.24	2.13	41.33
1900	3.73	4.03	4.80	2.89	3.12	4.20	2.41	.33	5.43	5.18	(1.94)	(2.96)	41.02
1901	2.20	.76	3.43	6.31	8.21	7.35	6.02	10.90	3.59	.71	1.07	6.71	57.26

STANARDSVILLE, VA.

Normal	3.32	3.11	3.64	3.02	4.61	3.38	4.57	4.63	3.72	3.58	2.39	2.82	42.79
1896	2.41	4.79	2.74	1.83	3.73	3.13	7.41	2.97	5.41	.11	5.34	T.	39.87
1897	1.88	5.08	2.51	1.86	4.45	3.51	7.70	2.27	.65	3.81	2.68	4.40	46.80
1898	2.49	.65	4.52	3.24	5.72	2.51	5.22	6.06	3.11	12.01	2.46	4.20	52.19
1899	4.11	4.43	6.25	1.47	3.55	2.74	3.15	4.14	5.17	2.87	1.52	2.10	41.50
1900	3.88	3.56	(3.64)	2.77	1.13	5.87	2.03	.97	4.40	4.07	(2.39)	(3.10)	37.81
1901	1.62	T.	4.34	6.52	9.30	2.76	5.51	8.90	3.08	(3.58)	1.70	4.90	52.21

STAUNTON, VA.

Normal	2.61	2.93	3.40	2.91	4.55	3.98	3.29	3.55	3.84	2.97	2.23	2.66	38.92
1896	2.55	3.81	4.41	1.33	4.13	6.58	6.10	3.92	8.08	.23	5.01	T.	46.15
1897	.92	3.99	2.56	1.56	5.75	2.18	3.70	2.30	.73	2.84	2.14	3.31	31.98
1898	2.89	.55	3.10	2.95	4.82	2.16	4.41	5.16	2.22	7.13	1.74	3.00	40.13
1899	3.46	4.89	6.15	1.56	3.64	1.39	1.33	5.46	3.89	3.06	.90	1.14	36.87
1900	3.01	3.38	3.45	2.27	3.19	5.66	2.57	2.34	3.64	4.58	2.88	2.05	39.02
1901	2.29	.32	3.39	8.42	7.88	4.97	5.39	6.71	3.46	.51	1.40	6.44	51.18

Depth of run-off, in inches, from the drainage basin of north (of James) River at Glasgow, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.63	3.99	2.32	1.19	2.83	0.62	0.51	0.31	0.23	0.28	0.32	0.72	13.95
1898	.99	.53	1.28	2.00	2.38	.80	.72	2.38	.41	2.48	1.23	1.39	16.59
1899	2.05	2.83	[a]4.44	1.03	.77	.30	.24	.28	.31	.24	.31	.33	13.13
1900	1.41	2.32	2.91	1.29	.82	1.36	.48	.31	.37	.56	1.03	1.22	14.08
1901	1.04	.43	2.44	4.20	2.77	3.00	1.18	2.49	.97	.55	.39	4.50	23.96
Average	1.22	2.12	2.68	1.94	1.91	1.22	.63	1.15	.46	.82	.66	1.63	16.34

[a] Approximate.

Depth of run-off, in inches, from the drainage basin of James River at Buchanan, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.48	3.75	1.90	0.88	1.86	0.52	0.54	0.36	0.23	0.23	0.20	0.54	11.49
1898	1.06	.55	1.29	1.93	1.98	.48	.47	1.84	.49	1.98	1.08	1.20	14.35
1899	1.83	3.03	4.53	1.68	1.99	1.05	.30	.26	.36	.21	.24	.38	15.86
1900	1.27	2.10	3.21	1.44	.66	1.17	.42	.23	.32	.84	2.01	1.65	15.32
1901	1.53	.62	2.12	4.65	3.30	3.03	1.45	2.62	.87	.40	.28	3.77	24.64
Average	1.23	2.01	2.61	2.12	1.96	1.25	.64	1.06	.45	.73	.76	1.51	16.33

Depth of run-off, in inches, from the drainage basin of James River at Cartersville, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1899	4.55	3.35	4.55	1.67	1.29	0.62	0.32	0.54	0.52	0.31	0.59	0.51	18.82
1900	1.53	1.96	2.55	1.81	.89	1.37	.47	.25	.30	.67	1.13	1.48	14.41
1901	1.71	.61	1.52	4.38	3.29	3.08	1.43	3.08	1.23	.69	.50	2.95	24.47
Average	2.60	1.97	2.87	2.62	1.82	1.69	.74	1.29	.68	.56	.74	1.65	19.23

Depth of run-off, in inches, from the drainage basin of Appomattox River at Mattoax, Va.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	.....	.....	.....	.....	.....	.....	.....	.....	0.26	0.28	0.35	0.59	.....
1901	1.52	0.47	0.80	3.64	3.22	0.64	0.81	4.12	.67	.52	.47	2.26	19.61
Average	1.52	.47	.80	3.64	3.22	.64	.81	4.12	.67	.52	.47	2.26	19.61

Rainfall and run-off in James River Basin.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Ashland	42.86	36.15	42.89	43.34	45.21	37.45	49.85
Barbourville	43.61	42.10	38.78	43.96	41.53	38.05	57.26
Bedford City	41.69	44.53	31.68	47.96	44.85	42.35	55.50
Bonair	43.73	41.94	41.69	42.49	44.20	36.87	52.66
Buckingham	41.95	39.63	34.71	36.42	48.90	40.36	52.26
Christiansburg	37.47	39.36	36.74	38.00	42.60	46.01	.....
Clifton Forge	35.28	37.09	37.92	37.46	24.68	37.91	36.63
Dale Enterprise	42.62	34.73	32.99	50.38	31.99	37.52	56.29
Doswell	35.46	.....	32.59	37.82	37.58	27.56	41.75
Farmville	40.95	.....	34.83	44.22	47.16	39.75	39.02
Fredericksburg	40.66	35.48	39.82	42.88	47.88	41.95	45.38
Hot Springs	39.97	41.13	35.54	51.88	42.13	41.85	55.45
Lexington	40.69	44.52	37.06	47.06	41.41	40.30	44.40
Lynchburg	43.99	46.64	40.08	49.93	52.91	47.10	54.81
Petersburg	45.02	42.78	37.56	36.44	45.71	41.71	45.86
Richmond	44.73	.....	.....	41.65	43.30	37.76	42.05
Salem	42.08	41.18	37.08	44.00	41.33	41.02	57.26
Stanardsville	42.79	39.87	40.80	52.19	41.50	37.81	52.21
Staunton	38.92	46.15	31.98	40.13	36.87	39.02	51.18
Average	41.29	40.83	36.93	43.59	42.20	39.60	49.38
RUN-OFF.							
North (of James) at Glasgow	15.29	18.14	13.95	16.59	13.13	[a]14.08	23.96
James at Buchanan	11.68	10.77	11.49	14.35	15.86	15.32	24.64
James at Cartersville	.....	.....	.....	.....	18.82	14.41	24.47
Appomattox at Mattoax	.....	.....	.....	.....	.....	.....	19.61
Average run-off	13.49	14.46	12.72	15.47	15.94	14.60	23.17
Percentage of rainfall	32.67	35.42	34.44	35.49	37.75	36.87	46.92

[a] Approximate.

SOUTHERN ATLANTIC COAST DRAINAGE.

Systematic measurements of discharge of many of the larger rivers of the Southern Atlantic States have been made during the year. The drainage areas of the rivers in that region are in general similar. Most of the streams rise in the southern Appalachian Mountains or their foothills. In the upper part of their courses they are rapid, with considerable fall. Across the Piedmont Plain their valleys are wide and their flow in general is sluggish, with occasional falls over rocky beds. Many of them have falls that could be utilized for water power, and it is largely to that end that data of the flow are being collected. In the study of water power it is important to know the flow and the fall. The fall can readily be determined by an engineer, but the variations in flow often require long and careful study. Gaging stations, to determine the latter, have been established on nearly all of the larger streams in the region, and it is hoped that in the near future our information of their fall will be extended.

The stations maintained by the survey in previous years were kept up during 1901 on the following rivers: On Roanoke River and tributaries; on Cape Fear, Yadkin, and Catawba rivers; on Savannah River and tributaries; on Oconee River and tributaries, and on Ocmulgee River. New stations were established in Georgia during 1901 on Middle Oconee River near Athens; on Oconee River at Barnett Shoals; on Apalachee River near Buckhead; on Alcovy River near Covington; and on Ocmulgee River near Flovilla.

The results for the year 1901, where available, are given on the following pages. In addition to these so-called permanent stations, many temporary stations are being maintained on streams in the Southern Appalachian region, the results for which will be found in the water-supply papers on operations at river stations.

Storms of considerable magnitude and duration during May and June, 1901, were the cause of high floods on the rivers draining from the Appalachian region into the Atlantic and the Gulf of Mexico. The damage caused by the freshets on some of the rivers was very heavy, particularly along the Catawba and Yadkin rivers, and along Cane Creek and Elkhorn Creek, in McDowell County, W. Va. Although the precipitation in these instances was unusually great, the rapidity and the violence of the run-off must be attributed in no small measure to the partial deforestation that has taken place at the headwaters of these streams. The accompanying illustrations will furnish an idea of the nature of the havoc wrought in some localities.

ROANOKE RIVER.

Estimated monthly discharge of Staunton River at Randolph, Va.

[Drainage area, 3,076 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	8,625	1,120	1,878	0.61	0.68
October	17,900	1,350	2,597	.84	.97
November	13,100	2,025	2,938	.96	1.07
December	18,600	2,550	3,944	1.28	1.48
1901.					
January	35,980	2,550	5,362	1.74	2.01
February	3,860	2,410	2,948	.98	1.02
March	14,850	2,340	4,000	1.30	1.50
April	36,910	3,580	9,620	3.13	3.49
May	37,940	2,980	8,148	2.65	3.16
June	9,750	3,140	4,759	1.55	1.73
July	30,980	2,690	6,259	2.03	2.34
August	45,100	2,620	13,185	4.29	4.94
September	6,955	2,620	3,998	1.30	1.45
October	6,725	2,795	3,346	1.09	1.26
November	5,260	2,725	2,984	.97	1.08
December	75,100	2,830	9,621	3.13	3.61
The year	75,100	2,340	6,186	2.01	27.59

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 239; rating table on page 319 of same paper.

Estimated monthly discharge of Dan River at South Boston, Va.

[Drainage area, 2,750 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	7,605	700	1,430	0.52	0.58
October	6,500	1,200	1,842	.67	.77
November	4,600	1,360	1,804	.66	.74
December	15,100	2,075	2,785	1.01	1.16

Estimated monthly discharge of Dan River at South Boston, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,965	1,860	3,387	1.23	1.42
February	2,675	1,600	2,042	.74	.77
March	25,000	1,600	3,504	1.27	1.46
April	38,800	2,375	6,382	2.32	2.59
May	45,600	2,300	7,297	2.65	3.06
June	3,100	1,925	2,292	.83	.93
July	44,200	2,150	6,132	2.23	2.58
August	36,600	1,860	9,866	3.59	4.14
September	5,100	2,150	2,902	1.06	1.18
October	4,100	1,860	2,353	.86	.99
November	3,730	1,730	2,032	.74	.83
December	51,200	2,000	6,875	2.50	2.89
The year	51,200	1,600	4,589	1.67	22.84

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 240; rating table on page 319 of same paper.

Estimated monthly discharge of Roanoke River at Roanoke, Va.

[Drainage area, 388 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,367	187	522	1.35	1.56
February	374	140	245	.63	.66
March	3,233	170	559	1.44	1.66
April	8,924	429	1,837	4.73	5.27
May	17,016	349	2,396	6.18	7.13
June	2,094	429	940	2.42	2.70
July	4,372	205	924	2.38	2.75
August	18,104	240	2,098	5.41	6.23
September	1,156	260	435	1.12	1.25
October	723	205	277	.71	.82
November	280	170	199	.51	.57
December	15,044	170	1,488	3.84	4.43
The year	18,104	140	993	2.56	35.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 241; rating table on page 319 of same paper.

Estimated monthly discharge of Roanoke River at Neal, N. C.

[Drainage area, 8,717 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,125	4,190	10,053	1.15	1.33
February	7,700	3,630	5,186	.59	.61
March	44,550	3,420	9,370	1.07	1.23
April	56,960	11,070	24,914	2.86	3.19
May	85,200	4,980	20,817	2.39	2.76
June	27,640	5,240	11,138	1.28	1.43
July	51,055	5,205	15,898	1.82	2.10
August	57,300	4,190	30,897	3.54	4.08
September	30,550	5,130	10,919	1.25	1.39
October	13,380	4,190	6,563	.75	.86
November	8,305	3,980	4,637	.53	.59
December	52,535	4,400	14,865	1.70	1.96
The year	85,200	3,420	13,763	1.58	21.53

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 242; rating table on page 320 of same paper.

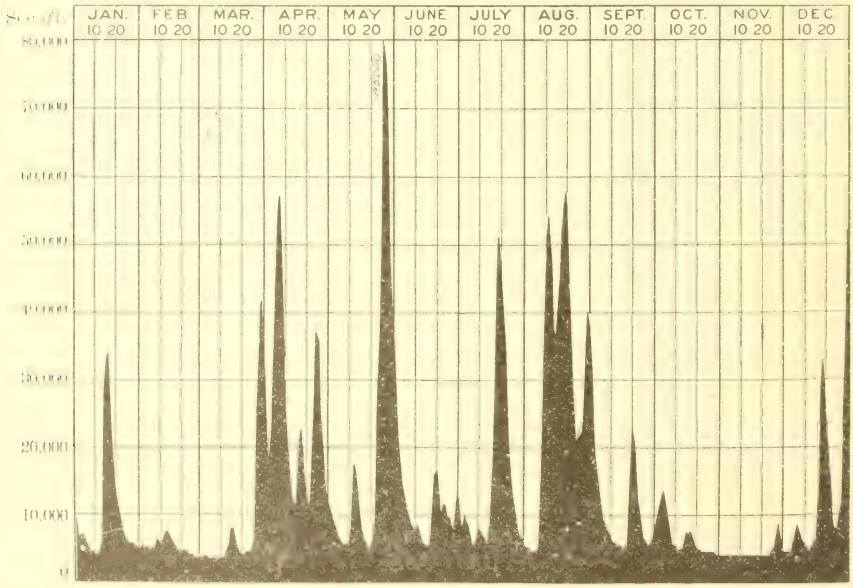


FIG. 14.—Discharge of Roanoke River at Neal, N. C., 1901.

CAPE FEAR RIVER.

Estimated monthly discharge of Deep River at Cumnock, N. C.

[Drainage area, 1,110 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
July (18 days)			274	0.25	0.17
August	394	72	138	.12	.14
September	3,990	116	308	.28	.31
October	274	80	139	.12	.14
November	4,550	106	368	.33	.37
December	5,190	126	878	.79	.91
1901.					
January	4,830	250	827	.75	.86
February	2,990	262	656	.59	.61
March	27,100	181	3,564	3.21	3.70
April	9,075	95	1,958	1.76	1.96
May	6,820	80	989	.89	1.03
June	9,918	334	2,129	1.92	2.14
July	13,540	322	2,500	2.25	2.60
August	14,135	322	4,179	3.76	4.34
September	10,950	298	1,805	1.63	1.82
October	1,125	322	434	.39	.45
November	334	250	286	.26	.29
December	16,696	274	1,824	1.64	1.89
The year	27,100	80	1,763	1.59	21.69

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 243; rating table on page 320 of same paper.

Estimated monthly discharge of Cape Fear River at Fayetteville, N. C.

[Drainage area, 4,493 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	7,120	1,600	3,048	0.68	0.78
February	4,850	1,560	2,659	.59	.61
March	28,050	1,200	4,209	.94	1.08
April	49,065	2,440	9,624	2.14	2.39
May	71,625	1,560	11,502	2.56	2.95
June	11,800	1,760	4,352	.97	1.08
July	37,675	1,520	8,072	1.80	2.08
August	43,450	1,440	13,965	3.11	3.59
September	41,350	1,600	7,296	1.62	1.81
October	4,450	1,400	2,342	.52	.60
November	2,440	1,400	1,555	.35	.39
December	27,200	1,440	3,828	.85	.98
The year	71,625	1,200	6,038	1.34	18.34

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 244; rating table on page 320 of same paper.

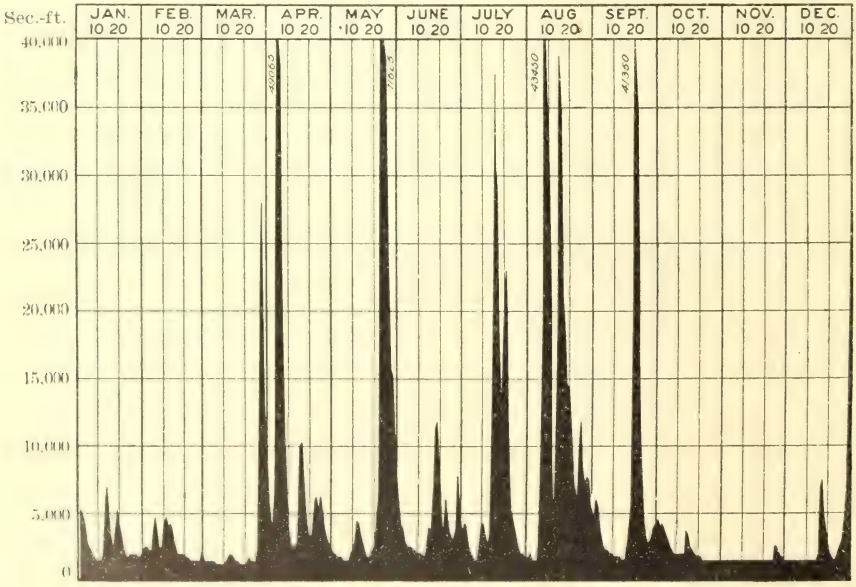


FIG. 15.—Discharge of Cape Fear River at Fayetteville, N. C., 1901.

A. WHEAT FIELD WASHED OUT AND COVERED WITH SAND BY FLOOD ON YADKIN RIVER NEAR ELKIN, N. C.

B. PLATE-GIRDER BRIDGE ON ELKHORN CREEK AT NORWOOD, W. VA., DEMOLISHED BY FLOOD.

YADKIN RIVER.

Estimated monthly discharge of Yadkin River at Salisbury, N. C.

[Drainage area, 3,399 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	31,180	2,925	5,284	1.55	1.79
February	6,195	2,420	3,507	1.03	1.07
March	37,780	2,585	5,922	1.74	2.01
April	81,030	4,180	13,787	4.06	4.53
May	70,870	4,000	11,152	3.28	3.78
June	32,220	4,540	10,950	3.22	3.59
July	29,200	3,820	8,455	2.49	2.87
August	44,132	3,640	16,509	4.86	5.60
September	16,120	4,360	6,764	1.99	2.22
October	13,420	3,640	5,116	1.51	1.74
November	6,380	3,100	3,683	1.08	1.20
December	104,640	3,280	12,506	3.68	4.24
The year	104,640	2,420	8,636	2.54	34.64

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 246; rating table on page 320 of same paper.

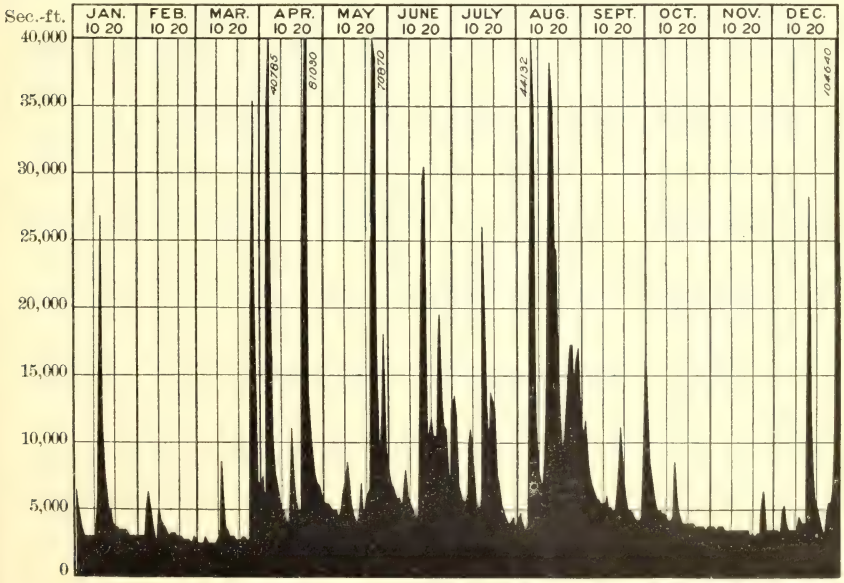


FIG. 16.—Discharge of Yadkin River at Salisbury, N. C., 1901.

CATAWBA RIVER.

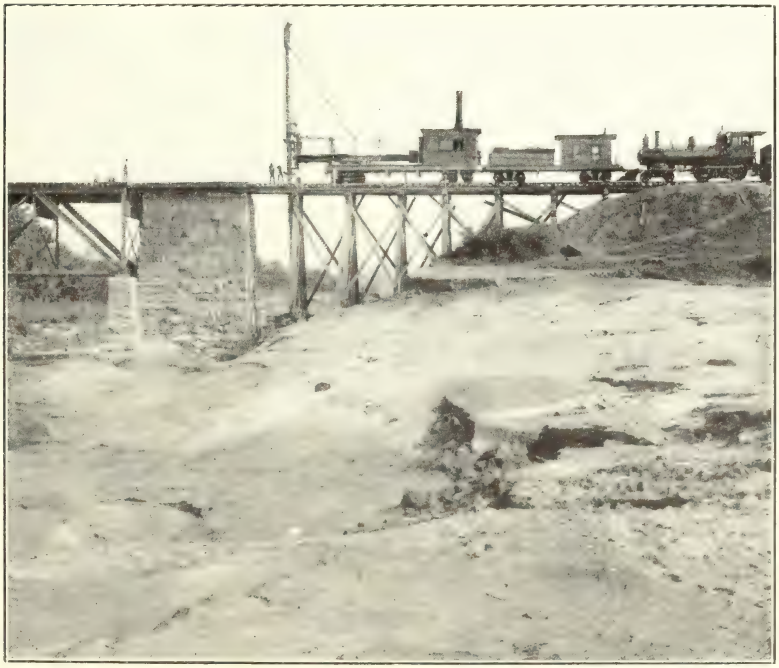
Estimated monthly discharge of Catawba River at Catawba, N. C.

[Drainage area, 1,514 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	17,240	2,720	3,777	2.49	2.87
February	4,175	2,720	3,009	1.99	2.07
March	38,375	2,855	5,130	3.39	3.91
April 1-20			9,911	6.55	4.87
May	81,500	3,150	8,260	5.46	6.29
June	24,540	2,810	5,358	3.54	3.95
July	6,655	2,275	3,383	2.23	2.57
August	40,250	2,450	10,326	6.82	7.87
September	6,590	2,495	3,493	2.31	2.58
October	4,120	2,315	2,601	1.72	1.98
November	3,500	2,000	2,311	1.53	1.71
December	45,875	2,090	5,830	3.85	4.44

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 247; rating table on page 320 of same paper.

A CATAWBA RIVER NEAR MORGANTON, N. C., AT SITE OF STEEL HIGHWAY BRIDGE DESTROYED BY FLOOD.



B. CATAWBA RIVER AT CATAWBA, N. C., SHOWING BANKS WASHED OUT BY FLOOD.

Estimated monthly discharge of Catawba River near Rockhill, S. C.

[Drainage area, 2,937 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	26,500	3,825	5,245	1.76	2.03
February	7,750	3,665	4,240	1.42	1.48
March	57,250	3,505	7,219	2.42	2.79
April	107,850	4,625	15,812	5.29	5.90
May	127,850	4,145	14,302	4.79	5.52
June	30,000	4,625	9,211	3.08	3.44
July	20,400	3,825	6,159	2.06	2.37
August	64,125	3,825	18,983	6.36	7.34
September	14,850	4,850	7,130	2.39	2.67
October	8,550	4,145	4,980	1.67	1.93
November	4,545	3,985	4,121	1.38	1.54
December	98,850	3,825	13,775	4.61	5.31
The year	127,850	3,505	9,265	3.10	42.32

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 248; rating table on page 320 of same paper.

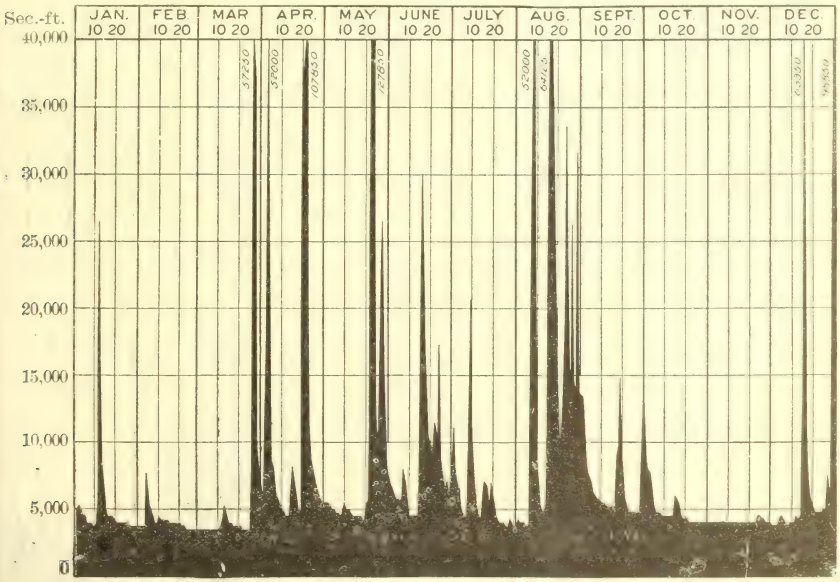


FIG. 17.—Discharge of Catawba River near Rockhill, S. C., 1901.

BROAD RIVER (OF THE CAROLINAS).

Estimated monthly discharge of Broad River (of the Carolinas) near Alston, S. C.

[Drainage area, 4,609 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	23,550	4,105	7,227	1.57	1.81
February	32,100	3,816	7,775	1.69	1.76
March	100,987	3,340	11,784	2.56	2.95
April	103,300	5,075	22,490	4.88	5.44
May	131,050	3,765	15,331	3.33	3.84
June	54,675	4,540	13,666	2.96	3.30
July	13,350	4,450	6,349	1.38	1.59
August	104,225	3,765	30,201	6.55	7.55
September	89,425	6,750	18,113	3.93	4.38
October	14,850	5,075	7,123	1.55	1.79
November	6,960	4,360	4,892	1.07	1.18
December	121,337	4,450	16,457	3.57	4.12
The year	131,050	3,340	13,451	2.92	39.71

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 250; rating table on page 320 of same paper.

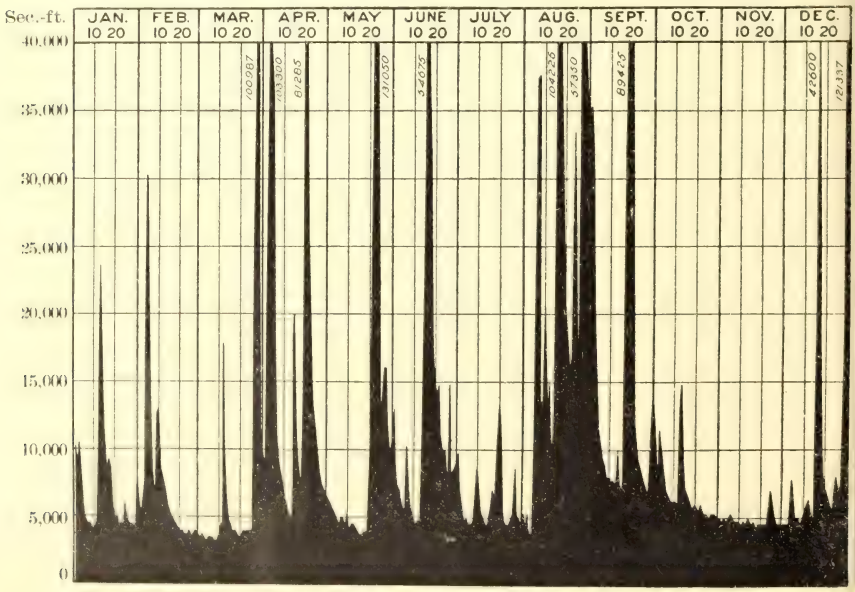


FIG. 18.—Discharge of Broad River (of the Carolinas) near Alston, S. C., 1901.

SALUDA RIVER.

Estimated monthly discharge of Saluda River at Waterloo, S. C.

[Drainage area, 1,056 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,670	780	1,834	1.74	2.01
February	7,166	672	2,066	1.96	2.04
March	10,668	843	2,203	2.09	2.41
April	11,212	1,046	3,382	3.20	3.57
May	10,906	650	2,539	2.40	2.77
June	12,810	1,114	3,136	2.97	3.31
July	2,474	750	1,491	1.41	1.63
August	12,028	430	4,949	4.69	5.41
September	12,878	1,556	3,795	3.59	4.01
October	3,732	1,148	1,862	1.76	2.03
November	1,964	526	1,261	1.19	1.33
December	12,368	526	2,709	2.57	2.96
The year	12,878	430	2,602	2.46	33.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 250; rating table on page 320 of same paper.

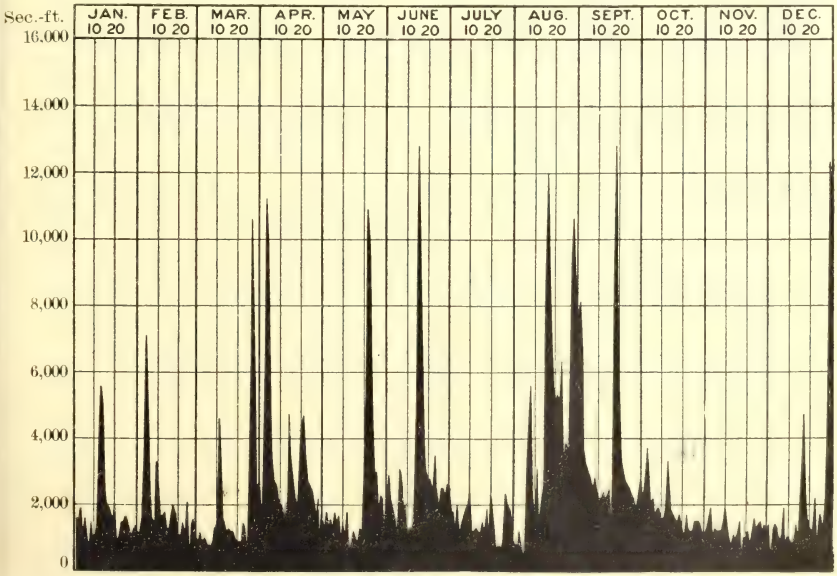


FIG. 19.—Discharge of Saluda River at Waterloo, S. C., 1901.

SAVANNAH RIVER.

Estimated monthly discharge of Tallulah River at Tallulah Falls, Ga.

[Drainage area, 191 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	.....	.....	[a] 810	4.24	4.89
February	1,365	587	687	3.60	3.75
March	4,550	461	976	5.11	5.89
April	3,850	770	1,424	7.46	8.32
May	5,250	540	1,065	5.58	6.43
June	1,050	540	817	4.28	4.78
July	875	429	625	3.27	3.77
August	4,690	391	1,608	8.42	9.71
September	2,030	640	1,358	7.11	7.93
October	613	429	511	2.68	3.09
November	429	391	398	2.08	2.32
December	6,650	391	1,013	5.30	6.11
The year	6,650	391	941	4.93	66.99

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 251; rating table on page 320 of same paper.

Estimated monthly discharge of Tugaloo River near Madison, S. C.

[Drainage area, 593 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	8,780	1,180	2,153	3.63	4.19
February	4,380	1,180	1,719	2.90	3.02
March	15,540	1,435	2,444	4.12	4.75
April	16,460	2,060	3,804	6.42	7.16
May	12,540	1,475	2,932	4.95	5.71
June	6,140	1,475	2,549	4.30	4.80
July	2,300	1,180	1,570	2.65	3.06
August	13,660	1,045	4,876	8.22	9.48
September	6,620	1,860	3,045	5.14	5.74
October	2,060	1,225	1,542	2.60	3.00
November	1,225	960	1,091	1.84	2.05
December	14,860	960	2,577	4.35	5.01
The year	16,460	960	2,525	4.26	57.97

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 252; rating table on page 320 of same paper.

Estimated monthly discharge of Savannah River near Calhoun Falls, S. C.

[Drainage area, 2,712 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	16,950	4,335	7,113	2.62	3.02
February	19,560	3,150	5,817	2.14	2.23
March	62,625	2,690	9,040	3.33	3.84
April	40,875	7,380	13,006	4.80	5.35
May	35,220	3,900	8,895	3.28	3.78
June	47,400	5,640	11,193	4.13	4.61
July	8,250	2,910	4,800	1.77	2.04
August	48,705	2,910	15,328	5.65	6.51
September	65,670	3,500	10,066	3.71	4.14
October	5,640	2,280	3,578	1.32	1.52
November	2,280	1,660	1,911	.70	.78
December	68,715	1,870	10,411	3.84	4.43
The year	68,715	1,660	8,430	3.10	42.25

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 253; rating table on page 320 of same paper.

Estimated monthly discharge of Savannah River at Augusta, Ga.

[Drainage area, 7,294 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	48,590	7,680	14,295	1.96	2.26
February	75,060	7,440	16,566	2.27	2.36
March	86,400	6,500	15,133	2.07	2.39
April	111,920	10,460	25,365	3.48	3.88
May	77,600	7,280	15,344	2.10	2.42
June	76,720	8,400	19,574	2.68	2.99
July	16,430	6,350	8,981	1.23	1.42
August	92,560	5,600	26,256	3.60	4.15
September	111,920	8,740	20,568	2.82	3.15
October	14,200	7,120	9,172	1.26	1.45
November	7,920	7,120	7,547	1.03	1.15
December	107,520	7,120	18,565	2.54	2.93
The year	111,920	5,600	16,447	2.25	30.55

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 254; rating table on page 320 of same paper.

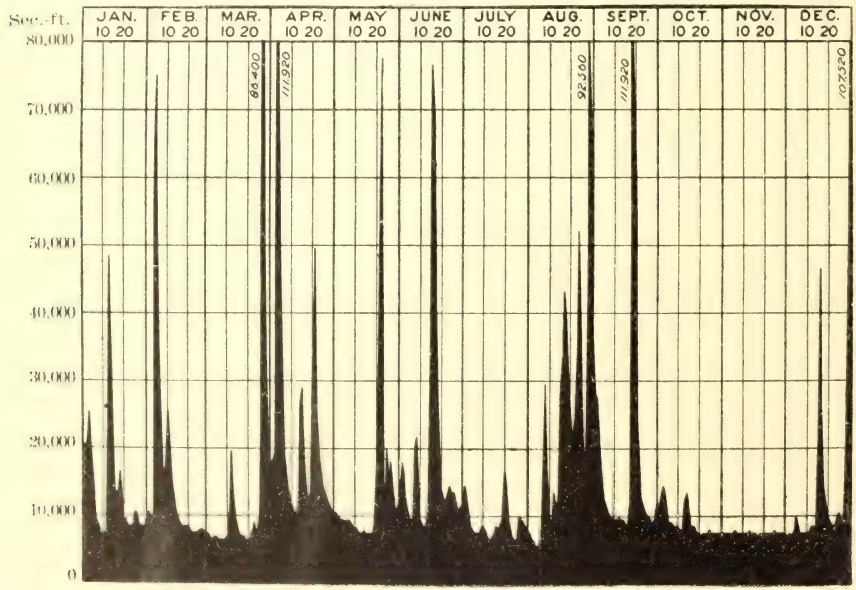


FIG. 20.—Discharge of Savannah River at Augusta, Ga., 1901.

Estimated monthly discharge of Broad River (of Georgia) near Carlton, Ga.

[Drainage area, 762 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	11,575	940	2,093	2.75	3.17
February	6,715	1,010	1,697	2.23	2.32
March	15,288	870	2,266	2.97	3.42
April	12,182	1,080	2,421	3.18	3.55
May	6,715	870	1,673	2.20	2.54
June	11,170	1,010	2,354	3.09	3.44
July	4,550	800	1,270	1.67	1.93
August	9,550	730	3,196	4.19	4.83
September	16,030	1,010	2,153	2.82	3.14
October	2,750	870	1,083	1.42	1.64
November	1,010	870	898	1.18	1.32
December	22,915	870	2,769	3.63	4.18
The year	22,915	730	1,989	2.61	35.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 255; rating table on page 321 of same paper.

ALTAMAHA RIVER.

Estimated monthly discharge of Middle Oconee River near Athens, Ga.

[Drainage area, 395 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
November	572	430	486	1.23	1.37
December	12,900	464	1,373	3.48	4.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 257; rating table on page 321 of same paper.

Estimated monthly discharge of Oconee River at Barnett Shoals, Ga.

[Drainage area, 835 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
August 13–31			4,092	4.90	3.46
September	9,542	824	1,763	2.11	2.35
October	1,958	780	916	1.10	1.27
November	918	780	801	.96	1.07
December	16,410	780	2,294	2.75	3.17

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 257; rating table on page 321 of same paper.

Estimated monthly discharge of Apalachee River near Buckhead, Ga.

[Drainage area, 440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
March	2,972	470	847	1.92	2.21
April	3,660	552	1,123	2.55	2.84
May	1,680	388	553	1.26	1.45
June	2,147	552	910	2.07	2.31
July	1,460	333	582	1.32	1.52
August	2,697	305	896	2.04	2.35
September	3,247	305	711	1.62	1.81
October	525	280	349	.79	.91
November	415	280	326	.74	.83
December	5,772	333	1,027	2.33	2.69

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 258; rating table on page 321 of same paper.

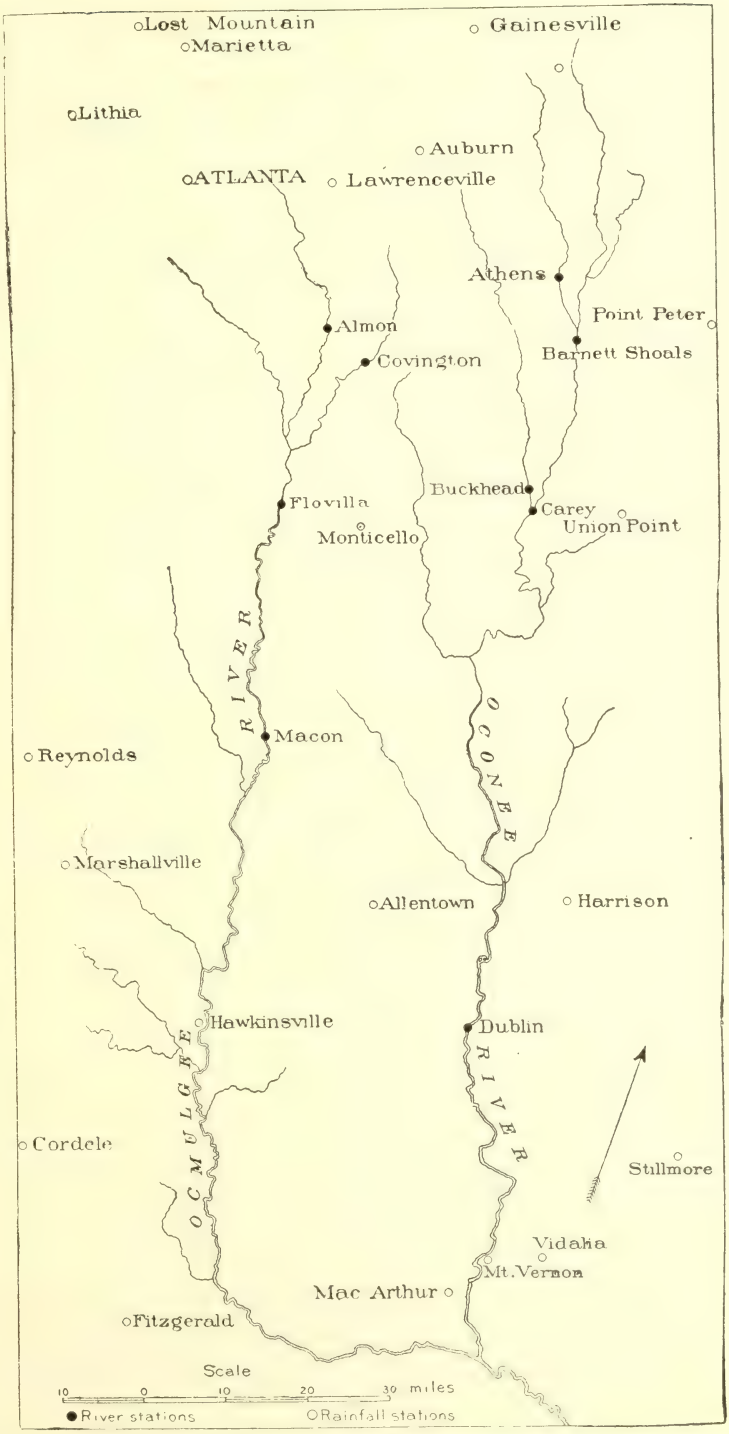


FIG. 21.—Location of river and rainfall stations in basins of Oconee and Ocmulgee rivers

Estimated monthly discharge of Oconee River near Dublin, Ga.

[Drainage area, 4,182 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	15,706	5,105	9,396	2.25	2.60
February	17,872	4,670	9,315	2.23	2.32
March	18,670	3,490	6,494	1.55	1.79
April	25,624	4,287	12,344	2.95	3.29
May	9,094	2,742	4,250	1.02	1.18
June	12,856	4,199	8,065	1.93	2.15
July	7,270	2,559	4,258	1.02	1.18
August	11,602	2,080	5,999	1.43	1.65
September	21,976	2,125	8,035	1.92	2.14
October	5,674	2,173	3,046	.73	.84
November	2,742	2,223	2,369	.56	.62
December	9,664	2,329	4,435	1.06	1.22
The year	25,624	2,080	6,500	1.55	20.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 259; rating table on page 321 of same paper.

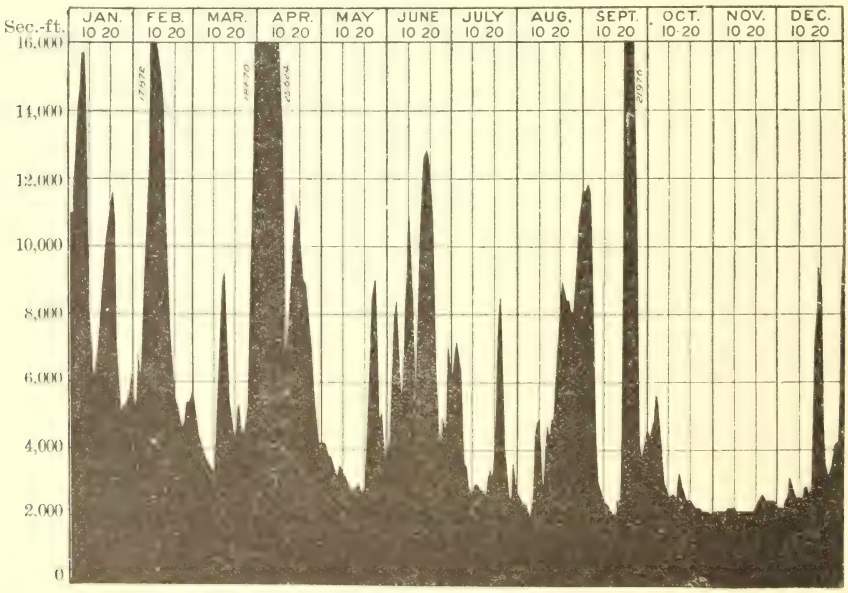


FIG. 22.—Discharge of Oconee River near Dublin, Ga., 1901.

Estimated monthly discharge of Alcovy River near Covington, Ga.

[Drainage area, 228 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
May	593	162	271	1.19	1.37
June	821	198	442	1.94	2.16
July	840	143	377	1.65	1.90
August	1,030	111	582	2.55	2.94
September	935	152	361	1.58	1.76
October	555	152	228	1.00	1.15
November	273	162	183	.80	.89
December	1,144	162	393	1.72	1.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 260; rating table on page 321 of same paper.

Estimated monthly discharge of Yellow River at Almon, Ga.

[Drainage area, 379 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	3,070	511	934	2.46	2.84
February	5,020	455	1,076	2.84	2.96
March	3,070	361	710	1.87	2.16
April	4,591	482	1,221	3.22	2.59
May	2,095	320	551	1.45	1.67
June	1,900	406	741	1.96	2.19
July	3,070	250	488	1.29	1.49
August	3,070	235	988	2.61	3.01
September	3,070	361	655	1.73	1.93
October	925	266	397	1.05	1.21
November	406	250	320	.84	.94
December	6,970	283	880	2.32	2.68
The year	6,970	235	947	1.97	25.67

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No 65, page 261; rating table on page 321 of same paper.

Estimated monthly discharge of Ocmulgee River near Florilla, Ga.

[Drainage area, 1,500 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
August	7,987	835	2,916	1.94	2.24
September	8,451	1,037	2,219	1.48	1.65
October	2,837	907	1,223	.82	.94
November	1,138	907	1,593	1.06	1.18
December	11,850	907	2,531	1.69	1.95

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 262; rating table on page 321 of same paper.

Estimated monthly discharge of Towaliga River near Juliette, Ga.

[Drainage area, 350 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,173	327	602	1.72	1.98
February	1,461	345	576	1.65	1.72
March	1,965	309	520	1.49	1.72
April	2,379	363	707	2.02	2.25
May	1,245	255	380	1.09	1.26
June	885	237	440	1.26	1.41
July	1,533	144	337	.96	1.11
August	1,893	154	531	1.52	1.75
September	1,245	154	360	1.03	1.15
October	417	165	209	.60	.69
November	309	154	185	.53	.59
December	1,857	190	475	1.36	1.57
The year	2,379	144	444	1.27	17.20

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 264; rating table on page 321 of same paper.

Estimated monthly discharge of Ocmulgee River at Macon, Ga.

[Drainage area, 2,425 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	13,010	2,244	4,908	2.02	2.33
February	21,880	2,185	5,165	2.13	2.22
March	22,720	1,693	4,586	1.89	2.18
April	34,060	2,244	6,556	2.70	3.01
May	13,590	1,546	2,806	1.16	1.34
June	6,704	1,693	3,323	1.37	1.53
July	19,780	1,314	2,521	1.04	1.20
August	16,420	1,184	4,686	1.93	2.23
September	29,440	1,227	3,913	1.61	1.80
October	3,081	978	1,412	.58	.67
November	1,314	978	1,104	.46	.51
December	30,280	1,059	4,324	1.78	2.05
The year	34,060	978	3,775	1.56	21.07

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 295; rating table on page 321 of same paper.

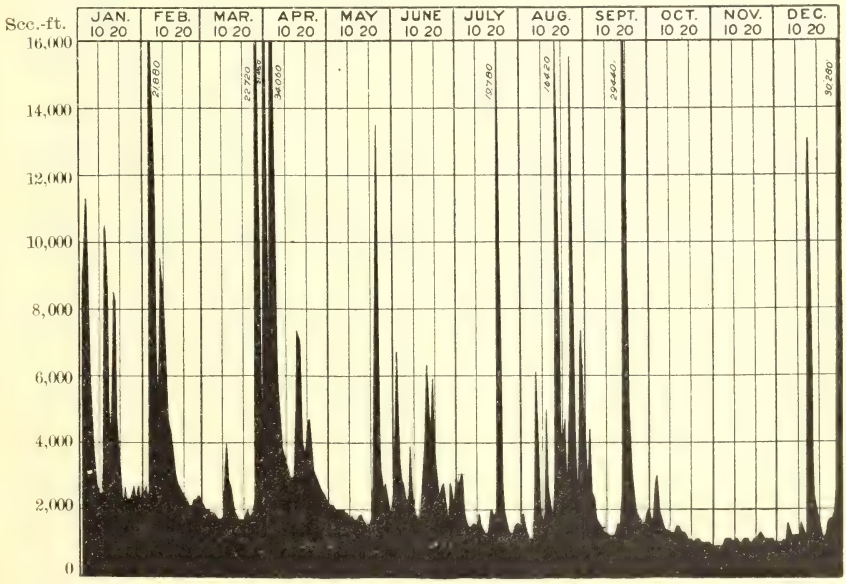


FIG. 23.—Discharge of Ocmulgee River at Macon, Ga., 1901.

PRECIPITATION IN THE BASINS OF OCONEE AND OCMULGEE RIVERS.

The principal observations of rainfall made within the Oconee and Ocmulgee river basins, considered here in conjunction, the two rivers being the principal tributaries of the Altamaha, are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 21, in connection with the points of river measurements which are located at Athens, Almon, Covington, Flovilla, Juliette, Macon, Barnett Shoals, Buckhead, Carey, and Dublin.

Location of rainfall stations in Oconee and Ocmulgee basins.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Atlanta	Fulton	Georgia	33 45	84 23	1,050	28–32
Athens	Clarke	do	33 58	83 23	850	21–27
Allentown	Wilkinson	do				5–6
Covington	Newton	do	33 37	83 49	748	8–12
Gillsville	Hall	do	34 13	83 56	1,052	11–13
Gainesville	do	do	34 16	83 47	1,227	15–29
Macon	Bibb	do	32 50	83 38	334	17–32
Marshallville	Macon	do				9–11
Point Peter	Oglethorpe	do	33 57	82 59	1,000	12–13

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1900, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers.

ATLANTA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	5.13	5.27	5.47	4.14	3.57	4.03	4.67	4.49	3.80	2.32	3.62	4.73	51.24
1896	3.12	3.04	3.29	.58	1.95	2.66	7.55	1.97	1.36	1.28	5.90	1.42	34.12
1897	3.48	4.59	5.74	5.06	.34	2.07	4.74	6.01	.14	1.80	2.29	3.00	39.26
1898	2.99	.62	4.09	5.15	1.35	.89	10.22	6.66	6.33	5.06	3.36	3.84	50.56
1899	3.69	6.62	5.38	1.71	1.21	1.46	6.42	3.15	2.27	3.71	2.65	4.15	42.42
1900	2.32	9.58	5.69	6.27	2.94	8.96	4.51	1.79	3.62	2.79	3.62	6.74	58.83
1901	5.95	4.04	5.71	5.27	7.55	3.10	5.37	9.83	3.76	.59	.99	7.61	59.77

ATHENS.

Normal	5.78	5.30	5.34	3.92	3.78	4.89	4.87	5.14	3.67	2.60	2.99	3.98	52.26
1896	(5.78)	(5.30)	(5.34)	(3.92)	1.78	3.93	10.31	1.00	.66	1.82	(2.99)	(3.98)	46.81
1897	(5.78)	(5.30)	(5.34)	(3.92)	.61	2.85	3.19	4.17	.64	3.12	1.10	2.83	38.85
1898	2.93	.66	3.55	5.58	2.48	1.53	5.43	5.73	6.36	7.40	3.85	3.81	49.31
1899	7.21	8.56	4.88	1.98	.83	1.55	2.50	3.93	1.45	3.59	1.35	2.78	40.61
1900	2.10	8.45	6.54	7.76	2.97	11.39	4.13	1.27	3.89	4.80	3.74	5.68	62.72
1901	4.14	3.57	4.78	5.59	4.90	6.53	3.51	17.87	3.30	1.05	.77	5.42	61.43

A. MONONGAHELA RIVER AT MORGANTOWN, W. VA

B. CHEAT RIVER, LOOKING UPSTREAM FROM CAMP EDEN, MONONGALIA COUNTY, W. VA.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers—Continued.

ALLENTOWN.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	3.23	6.70	4.74	3.94	2.08	3.13	5.26	5.03	3.55	3.86	4.01	4.21	49.74
1896	(3.23)	(6.70)	2.99	1.60	2.34	2.76	5.71	3.79	2.74	.72	7.49	5.21	45.28
1897	1.92	8.31	9.58	4.16	2.82	1.97	5.38	3.04	.73	2.51	.95	1.86	43.23
1898	1.48	1.02	1.13	7.22	.93	2.29	6.66	7.35	4.99	8.24	6.44	2.99	50.74
1899	6.38	9.32	3.13	3.15	1.72	1.69	3.50	3.26	.40	7.12	1.52	2.86	44.05
1900	2.42	10.26	5.57	4.10	2.59	6.96	6.03	3.11	1.90	3.61	6.61	8.06	61.22
1901	3.96	4.59	6.07	3.41	(2.08)	(3.13)	4.28	9.63	10.54	.97	1.03	4.26	53.95

COVINGTON.

Normal	4.44	5.02	4.96	4.94	2.79	4.04	4.96	6.09	2.69	3.03	2.81	4.33	50.10
1896	4.59	2.67	2.95	2.94	1.88	3.71	7.24	3.16	.90	2.62	9.78	1.11	43.55
1897	2.51	6.27	7.58	4.29	.95	2.68	3.52	5.44	.98	2.98	1.32	3.07	41.59
1898	3.86	1.06	3.59	5.93	1.98	1.46	10.20	10.69	5.33	9.55	4.04	4.85	62.54
1899	8.06	8.38	3.71	2.66	3.26	2.16	2.66	2.96	1.54	4.62	2.46	3.14	45.61
1900	2.35	10.46	3.40	7.54	2.21	14.78	4.08	5.16	4.08	1.90	3.69	7.66	67.31
1901	3.89	3.95	6.56	4.32	5.99	4.28	3.34	10.75	4.49	.61	.50	7.83	56.51

GILLSVILLE.

Normal	4.47	5.08	5.39	3.94	3.26	4.14	5.88	5.13	4.17	2.44	2.54	3.26	49.70
1896	4.45	2.14	2.11	.80	4.68	2.82	7.62	1.48	1.48	1.57	6.13	.40	35.68
1897	4.26	5.40	6.50	6.62	.00	2.48	10.94	2.95	a.00	5.11	1.83	3.91	50.00
1898	1.26	.36	3.54	4.20	1.03	2.64	6.75	7.78	10.13	8.18	3.17	3.54	52.58
1899	4.28	8.87	8.63	2.32	2.35	1.94	2.92	3.48	.53	2.37	2.80	3.61	44.10
1900	3.42	10.77	5.72	8.10	2.94	8.82	3.42	1.36	3.04	4.07	3.25	3.20	58.11
1901	6.44	3.43	6.50	6.20	6.11	5.89	5.57	11.73	5.38	.62	.10	6.14	64.11

GAINESVILLE.

Normal	5.96	6.34	6.78	4.30	3.39	4.67	5.04	6.03	3.99	2.74	3.71	5.24	58.19
1896	(5.96)	(6.34)	(6.78)	(4.30)	1.53	2.08	10.61	.77	1.62	(2.74)	6.77	2.02	51.52
1897	4.40	4.89	6.90	(4.30)	1.15	3.03	14.43	2.48	.05	2.67	3.46	2.78	50.54
1898	3.24	.79	4.41	5.29	1.03	1.23	12.12	9.58	6.71	7.30	3.58	3.37	58.65
1899	4.11	8.17	10.46	3.76	1.46	3.41	2.40	4.10	.40	2.43	2.82	4.49	48.01
1900	2.97	8.84	6.75	5.76	1.31	12.09	3.88	1.34	1.49	2.66	3.16	(5.24)	55.49
1901	8.02	3.53	6.69	5.84	6.35	6.89	5.47	13.58	4.65	1.24	.15	6.37	68.78

MACON.

Normal	3.83	4.50	5.82	3.94	3.03	4.23	4.78	4.89	2.68	2.10	3.03	4.45	47.28
1896	3.58	5.85	3.47	1.73	1,82	3.29	6.16	5.66	.68	1.58	7.09	5.01	45.92
1897	1.95	8.33	10.58	3.30	.87	6.16	5.10	3.37	1.12	.70	(3.03)	(4.45)	48.96
1898	(3.83)	(4.50)	(5.82)	(3.94)	.45	2.63	6.15	8.76	4.17	6.60	(3.03)	(4.45)	54.33
1899	(3.83)	(4.50)	(5.82)	a3.11	1.83	1.61	2.47	1.94	1.61	5.20	1.73	3.45	37.10
1900	1.87	7.64	3.68	4.80	2.97	6.69	3.26	5.93	1.25	1.27	4.53	5.89	49.78
1901	3.53	3.91	6.94	3.86	2.85	3.82	1.15	3.95	4.64	1.59	.42	5.37	42.03

a Approximate.

Precipitation at stations in drainage basins of Oconee and Ocmulgee rivers—Continued.

MARSHALLVILLE.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	4.22	6.23	5.75	4.17	2.36	3.72	5.62	5.19	2.45	3.08	2.95	4.28	50.02
1896	5.25	8.08	4.15	3.60	3.10	2.04	12.56	2.60	1.17	2.15	8.78	4.75	58.23
1897	1.93	8.85	10.06	5.57	.96	5.87	3.20	4.10	1.16	1.02	.70	2.83	46.25
1898	1.35	1.19	2.00	9.12	1.19	3.76	6.84	9.27	1.34	7.83	6.79	4.19	54.87
1899	6.22	6.50	2.91	4.99	1.46	.96	2.89	3.59	.72	8.24	1.59	2.87	42.94
1900	2.51	10.72	4.25	4.02	1.10	4.38	4.74	3.30	.44	2.68	4.20	8.66	51.00
1901	4.53	3.98	6.78	3.28	4.41	6.57	2.22	6.68	9.38	2.55	1.06	5.65	57.09

POINT PETER.

Normal	5.09	5.16	5.27	3.83	2.75	4.03	5.44	5.80	3.68	2.87	3.12	3.57	50.61
1896	5.40	4.60	3.35	2.90	2.55	1.45	8.65	1.10	1.25	2.35	6.60	[a]3.15	43.35
1897	4.06	6.50	5.68	6.51	.96	3.91	4.37	6.74	[a]2.05	2.21	3.00	3.05	49.04
1898	3.10	.70	4.25	5.38	.17	1.82	11.51	8.74	2.59	8.79	4.58	3.62	55.25
1899	7.25	8.19	5.00	1.99	.68	2.06	2.54	4.27	1.14	4.28	2.69	3.14	43.23
1900	1.85	8.34	4.54	6.27	3.47	12.71	6.90	.73	4.74	2.89	3.62	5.69	61.75
1901	4.08	3.68	5.12	5.12	6.22	4.18	2.84	15.67	7.35	.54	.87	6.86	62.53

[a] Approximate.

Depth of run-off, in inches, from the drainage basin of Yellow River at Almon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1900	1.30	4.10	2.93	4.21	1.89	4.09	1.73	1.08	1.45	1.13	1.12	2.46	27.49
1901	2.84	2.96	2.16	2.59	1.67	2.19	1.49	3.01	1.93	1.21	.94	2.68	25.67
Average	2.07	3.53	2.54	3.40	1.78	3.14	1.61	2.04	1.69	1.17	1.03	2.57	26.57

Depth of run-off, in inches, from the drainage basin of Middle Oconee River at Athens.

Year.	Nov.	Dec.
1901	1.37	4.01

Depth of run-off, in inches, from the drainage basin of Apalachee River at Buckhead.

Year.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	2.21	3.84	1.45	2.31	1.52	2.35	1.81	0.91	0.83	2.69

Depth of run-off, in inches, from the drainage basin of Oconee River at Barnett Shoals.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	3.46	2.35	1.27	1.07	3.17

Depth of run-off, in inches, from the drainage basin of Alcovy River at Covington.

Year.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	1.37	2.16	1.90	2.94	1.76	1.15	0.89	1.98

Depth of run-off, in inches, from the drainage basin of Oconee River at Dublin.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1898	.....	.....	0.71	1.34	0.49	0.32	0.85	1.57	2.84	2.05	1.90	2.02	.....
1899	2.96	3.73	3.36	2.04	.94	.50	.46	.58	.44	.72	.45	.84	17.02
1900	.97	2.99	2.73	2.53	1.31	2.23	1.76	.63	.64	.61	.86	1.61	18.87
1901	2.60	2.32	1.79	3.29	1.18	2.15	1.18	1.65	2.14	.84	.62	1.22	20.98
Average	2.18	3.01	2.15	3.30	.98	1.30	1.06	1.11	1.52	1.06	.96	1.42	19.05

Depth of run-off, in inches, from the drainage basin of Ocmulgee River at Flovilla.

Year.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	2.24	1.65	0.94	1.18	1.95

Depth of run-off, in inches, from the drainage basin of Towaliga River at Juliette.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1901	1.98	1.72	1.72	2.25	1.26	1.41	1.11	1.75	1.15	0.69	0.59	1.57	17.20

Depth of run-off, in inches, from the drainage basin of Ocmulgee River at Macon.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.64	1.83	4.22	2.51	0.81	0.79	0.91	0.84	0.32	0.30	0.36	0.51	14.04
1898	.62	.42	.60	1.20	.44	.30	.78	2.20	2.77	2.72	1.70	1.69	15.44
1899	2.66	3.50	2.62	2.06	1.00	.61	.56	.51	.40	.63	.46	.75	15.76
1900	.73	4.16	2.21	3.22	1.36	3.78	1.72	.95	1.18	.89	1.06	1.94	23.20
1901	2.33	2.22	2.18	3.01	1.34	1.53	1.20	2.23	1.80	.67	.51	2.05	21.07
Average	1.40	2.43	2.37	2.40	.99	1.40	1.03	1.35	1.29	1.04	.82	1.39	17.91

Depth of run-off, in inches, from the drainage basin of Oconee River at Carey.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	1.81	2.25	2.61	1.19	0.97	0.65	1.16	0.81	0.38	0.63	0.69	0.95	14.10
1898	1.15	.83	1.12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Average	1.48	1.54	1.86	1.19	.97	.65	1.16	.81	.38	.63	.69	.95	12.31

Rainfall and run-off in Oconee and Ocmulgee basins.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Atlanta	51.24	34.12	39.26	50.56	42.42	58.83	59.77
Athens	52.26	46.81	38.85	49.31	40.61	62.72	61.43
Allentown	49.74	45.28	43.23	50.74	44.05	61.22	53.95
Covington	50.10	43.55	41.59	62.54	45.61	67.31	56.51
Gillsville	49.70	35.68	50.00	52.58	44.10	58.11	64.11
Gainesville	58.19	51.52	50.54	58.65	48.01	55.49	68.78
Macon	47.28	45.92	48.96	54.33	37.10	49.78	42.03
Marshallsville	50.02	58.23	46.25	54.87	42.94	51.00	57.09
Point Peter	50.61	43.35	49.04	55.25	43.23	61.75	62.53
Average	51.02	44.94	45.30	54.31	43.12	58.47	58.47
RUN-OFF.							
Almon	26.57					27.49	25.67
Dublin	19.05				17.02	18.87	20.98
Juliette	17.20						17.20
Macon	17.91		14.04	15.44	15.76	23.20	21.07
Carey	12.31		14.10				
Average run-off	18.61		14.07	15.44	16.39	23.19	21.23
Percentage of rainfall	36.48		31.06	28.43	38.01	39.66	36.31

EASTERN GULF DRAINAGE.

The rivers flowing into the eastern portion of the Gulf of Mexico are for the most part of a character similar to those in the Southern Atlantic drainage, though in their lower courses their flow is usually more sluggish. Regular gaging stations have been maintained during the year 1901 as follows: On Flint River at Woodbury, Ga., and Albany, Ga.; on Chattahoochee River near Gainesville, Ga., near Buford, Ga., at Oakdale, Ga., and at West Point, Ga.; on Etowah River at Canton, Ga.; Coosawattee River at Carters, Ga.; on Oostanaula River at Resaca, Ga.; on Coosa River at Rome, Ga., near Riverside, Ala., and at Locks Nos. 4 and 5, Alabama; on Talladega Creek at Nottingham, Ala.; on Hillabee Creek near Alexander City, Ala.; on Big Sandy Creek near Dadeville, Ala.; on Tallapoosa River near Sturdevant, Ala., near Susanna, Ala., and near Milstead, Ala.; on Alabama River at Montgomery, Ala., and at Selma, Ala.; on Cahaba River at Centerville, Ala.; on Mulberry Fork of Black Warrior River near Cordova, Ala.; on Black Warrior River at Tuscaloosa,

Ala.; on Tombigbee River at Columbus, Miss., and at Epes, Ala.; and on Pearl River at Jackson, Miss. The locations of the river stations in the Apalachicola and Mobile river basins are shown in figs. 24 and 36.

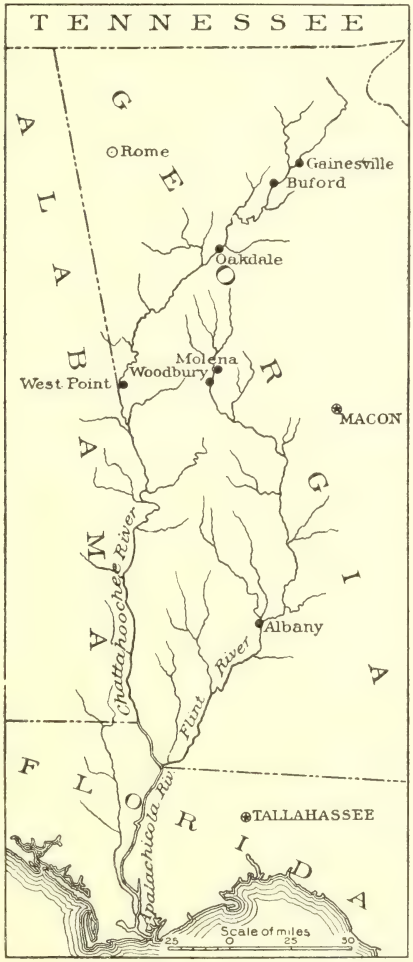


FIG. 24.—Drainage basin of Apalachicola River.

The floods that occurred during the year 1901 on the rivers of the southeastern States have been of marked severity, notably the high water of December 29 to 31, which resulted in the destruction of a number of masonry mill dams and other valuable property.

APALACHICOLA RIVER.

Estimated monthly discharge of Flint River at Woodbury, Ga.

[Drainage area, 988 square miles.]

Month.	Discharge in second-feet.			Run-off	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,840	1,370	2,803	2.84	3.27
February	6,820	1,120	2,395	2.42	2.52
March	7,100	800	1,774	1.80	2.08
April	9,900	890	2,818	2.85	3.18
May	13,260	580	2,285	2.31	2.66
June	3,740	580	1,617	1.64	1.83
July	2,200	460	780	.79	.91
August	10,460	460	2,467	2.50	2.88
September	5,980	460	1,249	1.26	1.41
October	3,040	430	679	.69	.80
November	650	460	526	.53	.59
December	14,100	530	2,005	2.03	2.34
The year	14,100	430	1,783	1.81	24.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 266; rating table on page 321 of same paper.

Estimated monthly discharge of Chattahoochee River near Buford, Ga.

[Drainage area, 1,050 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
June 24 to 30	.....	.....	3,554	3.38	0.88
July	8,768	1,700	2,507	2.39	2.76
August	18,064	1,450	4,985	4.75	5.48
September	10,224	2,300	3,031	2.89	3.22
October	3,105	1,560	1,863	1.77	2.04
November	1,630	1,450	1,537	1.46	1.63
December	23,100	1,450	3,624	3.45	3.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 268; rating table on page 321 of same paper.

Estimated monthly discharge of Chattahoochee River at Oakdale, Ga.

[Drainage area, 1,560 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	24,180	2,044	5,191	3.33	3.84
February	5,028	2,272	3,214	2.06	2.15
March	25,890	2,044	4,929	3.16	3.65
April	12,780	2,846	5,149	3.30	3.68
May	21,900	2,511	4,624	2.96	3.42
June	10,500	2,934	4,749	3.04	3.39
July	9,474	2,040	3,225	2.07	2.39
August	21,672	1,829	7,697	4.93	5.69
September	15,744	2,676	4,145	2.66	2.97
October	4,344	1,758	2,600	1.67	1.93
November	1,898	1,690	1,763	1.13	1.26
December	29,880	1,690	4,285	2.75	3.17
The year	29,880	1,690	4,298	2.75	37.54

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 269; rating table on page 322 of same paper.

Estimated monthly discharge of Chattahoochee River at West Point, Ga.

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	42,630	4,920	11,748	3.56	4.11
February	37,100	4,920	10,015	3.03	3.16
March	33,410	4,280	7,952	2.41	2.78
April	23,360	4,920	11,022	3.34	3.73
May	52,750	4,700	10,814	3.28	3.79
June	16,110	4,920	8,487	2.57	2.87
July	12,456	3,000	4,964	1.50	1.73
August	52,290	3,000	12,982	3.93	4.54
September	32,030	3,520	7,145	2.16	2.41
October	11,628	2,840	3,883	1.18	1.36
November	4,280	2,380	2,835	.86	.96
December	88,630	2,380	12,116	3.67	4.24
The year	88,630	2,380	8,664	2.62	35.68

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 270; rating table on page 322 of same paper.

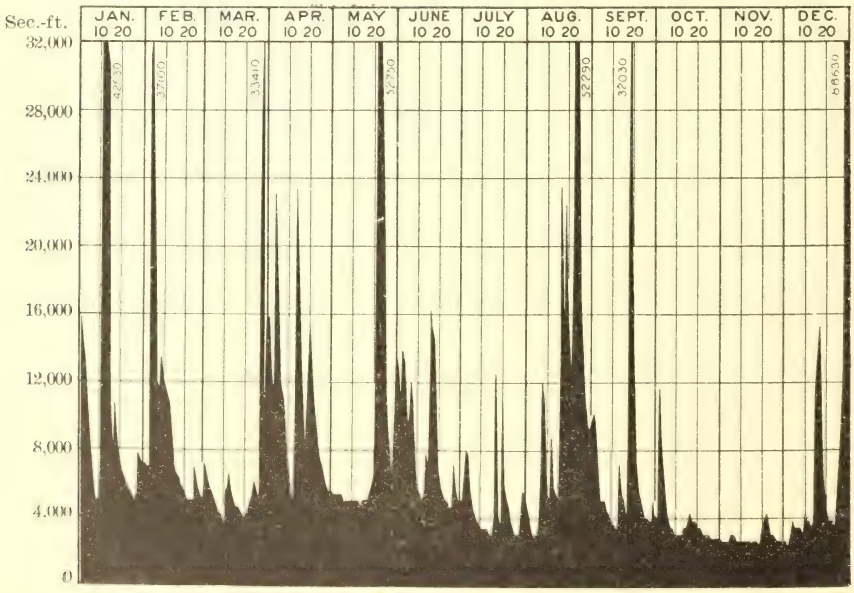


FIG. 25.—Discharge of Chattahoochee River at West Point, Ga., 1901.

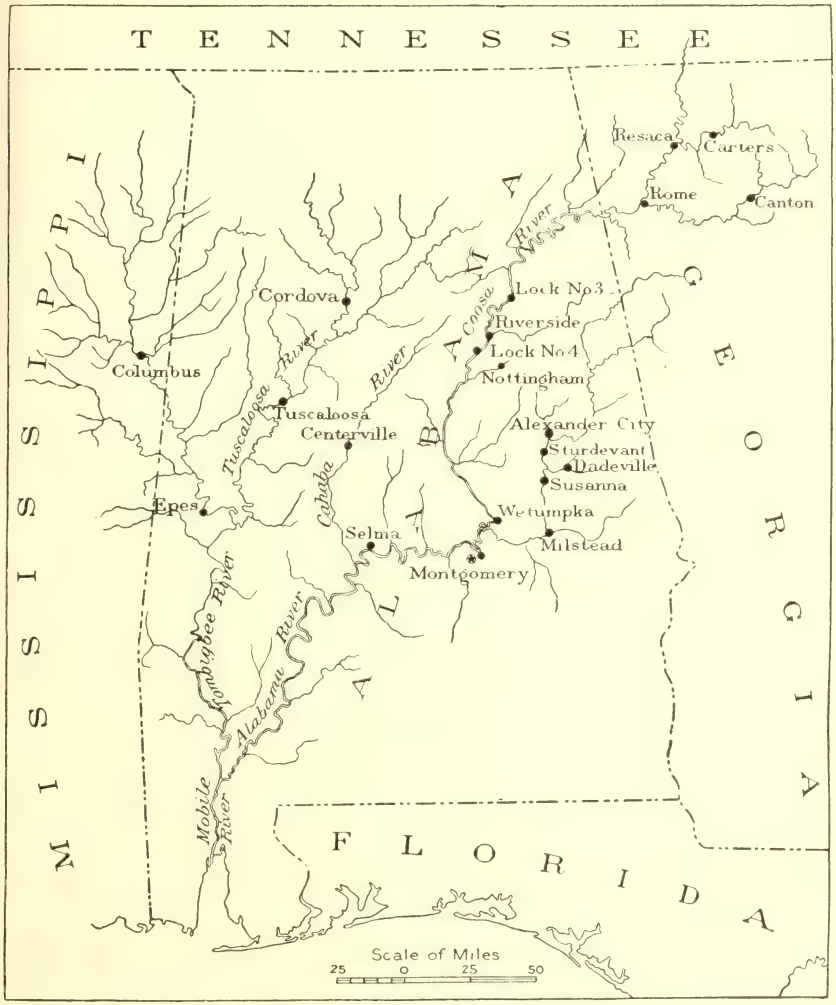


FIG. 26.—Drainage basin of Mobile River.

TALLAPOOSA RIVER.

Estimated monthly discharge of Hillabee Creek near Alexander City, Ala.

[Drainage area, 214 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
September	3,074	146	370	1.73	1.93
October	2,106	146	387	1.81	2.09
November	2,502	184	471	2.20	2.45
December	2,150	263	716	3.35	3.86
1901.					
January	3,030	566	1,198	5.60	6.46
February	3,646	566	920	4.30	4.48
March	1,798	434	617	2.88	3.32
April	3,910	566	911	4.26	4.75
May	1,226	434	624	2.92	3.37
June	830	230	439	2.05	2.29
July	1,006	169	357	1.67	1.93
August	1,446	138	535	2.50	2.89
September	654	138	249	1.16	1.29
October	786	138	181	.85	.98
November	169	138	148	.69	.77
December	4,350	138	526	2.46	2.84
The year	4,350	138	559	2.61	35.37

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 271, rating table on page 322 of same paper.

Estimated monthly discharge of Big Sandy Creek near Dadeville, Ala.

[Drainage area, 195 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	880	308	425	2.18	2.51
February	2,700	282	545	2.78	2.90
March	6,392	256	552	2.83	3.26
April	3,428	334	689	3.53	3.94
May	3,220	230	480	2.46	2.84
June	2,492	178	523	2.68	2.99
July	516	152	227	1.16	1.34
August	2,180	115	369	1.89	2.18
September	620	67	257	1.32	1.47
October	1,764	45	462	2.37	2.73
November	115	67	92	.47	.52
December	10,500	85	1,265	6.49	7.48
The year	10,500	45	490	2.51	34.16

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 273; rating table on page 322 of same paper.

Estimated monthly discharge of Tallapoosa River near Susanna, Ala.

[Drainage area, 2,610 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	53,780	5,630	13,265	5.08	5.86
February	44,780	5,630	11,303	4.33	4.51
March	26,330	3,850	7,546	2.89	3.31

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 274; rating table on page 322 of same paper.

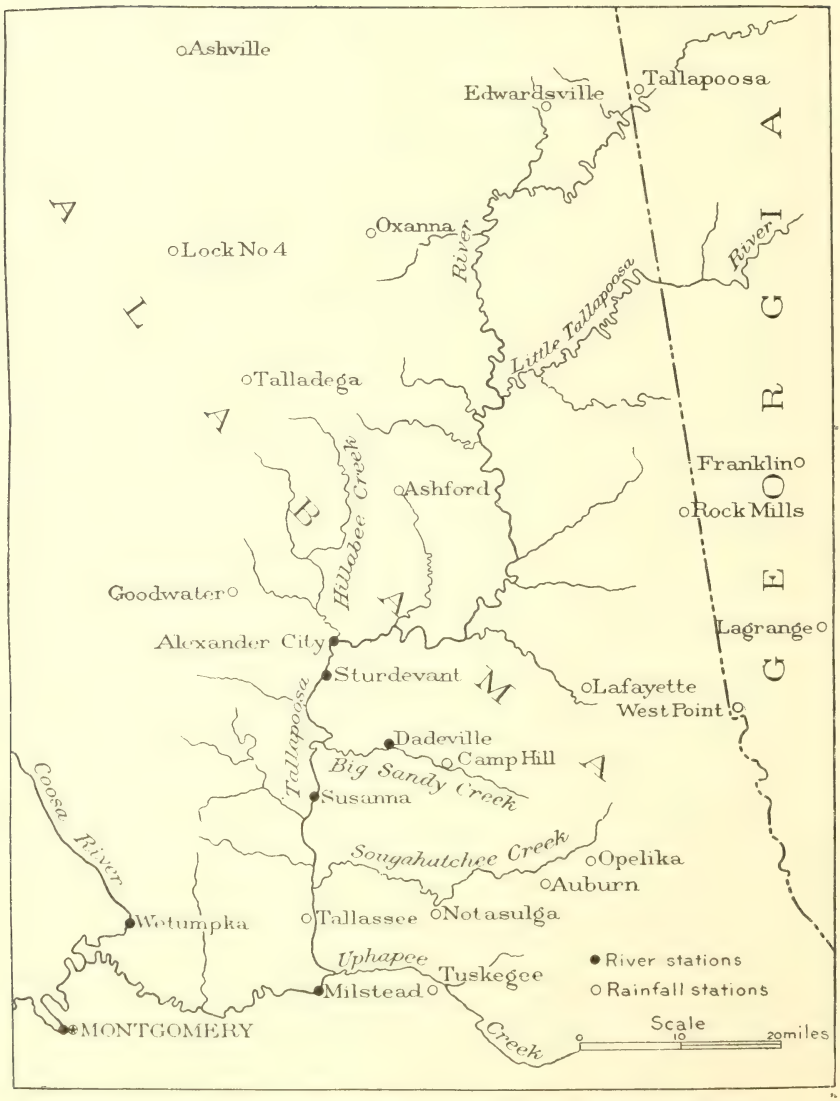


FIG 27.—Location of river and rainfall stations in basin of Tallapoosa River.

Estimated monthly discharge of Tallapoosa River near Milstead, Ala.

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	33,962	5,275	11,476	2.99	3.45
February	28,900	5,837	10,440	2.72	2.83
March	35,087	4,150	8,374	2.18	2.52
April	28,900	5,499	12,020	3.13	3.49
May	17,875	3,587	6,440	1.68	1.94
June	13,262	2,775	5,976	1.56	1.74
July	5,387	2,012	3,398	.88	1.01
August	23,275	2,012	5,904	1.54	1.78
September	9,887	1,675	3,137	.82	.91
October	6,849	1,562	2,364	.62	.71
November	2,237	1,562	1,855	.48	.54
December	[a] 70,000	1,843	8,282	2.16	2.49
The year	[a] 70,000	1,562	6,639	1.73	23.41

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 274; rating table on page 322 of same paper.

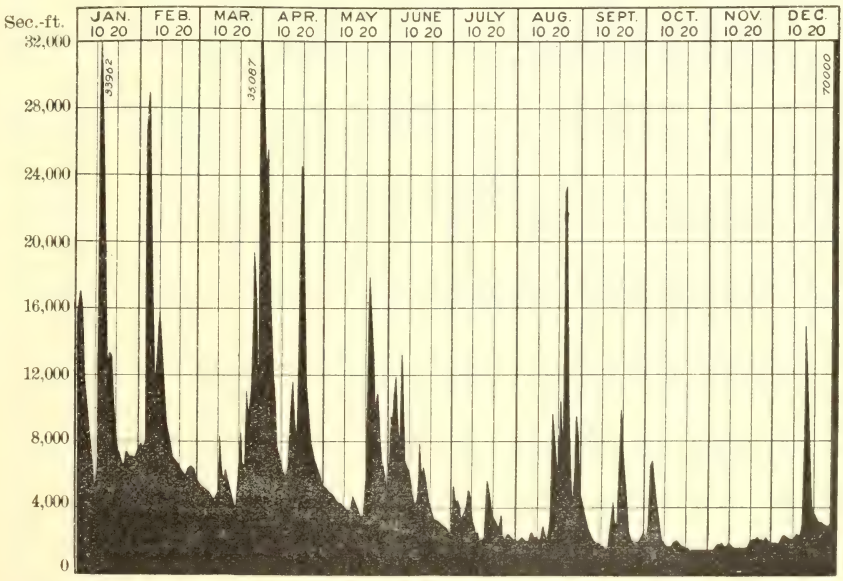


FIG. 28.—Discharge of Tallapoosa River near Milstead, Ala., 1901.

PRECIPITATION IN THE BASIN OF TALLAPOOSA RIVER.

The principal observations of rainfall made within the Tallapoosa River Basin are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 27, in connection with the points of river measurement which are located at Alexander City, Dadeville, Sturdevant, Susanna, and Milstead.

Location of rainfall stations in Tallapoosa River Basin.

Station.	County.	State.	Latitude.	Longitude.	Length of record.
			° ′	° ′	*Years.*
Ashville	St. Clair	Alabama			6–7
Goodwater	Coosa	do			6–9
Lock No. 4	Talladega	do			7–9
Opelika	Lee	do	32 38	85 25	6–22
Oxanna	Calhoun	do	32 23	86 18	9–11
Tallassee	Elmore	do			8–11
Wetumka	do	do			9–11

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made:

Precipitation at stations in drainage basin of Tallapoosa River.

ASHVILLE, ALA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	4.54	4.65	7.16	6.30	7.90	4.01	5.12	4.48	2.52	2.94	3.04	4.95	57.61
1896	4.42	3.78	4.48	4.21	2.35	3.14	2.22	1.20	1.89	1.09	4.78	1.11	34.67
1897	4.15	6.09	7.42	5.00	1.62	.96	5.17	2.63	.30	1.00	.77	7.04	42.15
1898	5 48	.80	3.40	5.37	.48	2.97	6.81	3.50	3.79	7.53	4.25	2.12	46.14
1899	4.82	6.27	11.14	4.21	1.28	2.46	8.27	3.43	.14	1.30	3.81	6.10	53.23
1900	2.65	7.40	6.35	12.56	2.93	11.98	6.45	1.44	5.35	6.73	3.83	3.41	71.08
1901	5.73	3.56	10.14	6.42	5.65	2.65	2.51	11.45	3.81	.56	1.63	10.87	64.98

GOODWATER, ALA.

Normal	4.50	5.00	5.68	4.17	2.28	4.37	5.63	4.64	2.18	3.17	3.32	4.62	49.56
1896	5.93	4.36	6.39	2.83	3.89	3.36	4.57	.69	3.05	1.05	3.14	.50	39.76
1897	3.20	4.33	8.38	3.90	.10	3.18	4.16	3.62	.94	.00	(3.32)	(4.62)	39.75
1898	1.45	.75	2.29	4.41	.16	4.92	8.18	9.02	1.37	3.76	5.32	2.20	43.83
1899	5.21	(5.00)	7.26	3.41	2.79	2.27	10.22	3.25	.26	2.21	2.70	5.85	50.43
1900	4.08	10.28	5.85	6.10	2.30	10.35	6.60	4.79	3.44	8.74	5.57	7.38	75.48
1901	7.11	5.26	5.01	4.39	5.31	4.78	6.14	8.54	2.67	1.28	1.84	7.76	60.09

Precipitation at stations in drainage basin of Tallapoosa River—Continued.

LOCK NO. 4, ALABAMA.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	5.88	5.23	5.60	4.86	2.85	4.33	6.11	4.62	2.20	2.59	2.82	4.25	51.34
1896	4.50	4.80	4.25	2.44	3.25	4.77	5.85	1.90	1.04	1.71	2.61	.87	37.99
1897	4.69	5.61	8.23	3.64	1.72	.43	4.51	3.45	.73	.74	1.96	6.74	42.45
1898	4.67	.69	4.11	4.18	1.49	5.27	5.60	4.35	2.44	6.82	4.84	2.01	46.47
1899	3.79	7.21	5.86	4.32	2.61	1.38	6.25	3.82	.06	1.19	3.61	7.01	47.11
1900	2.86	7.34	7.30	9.36	3.43	13.06	6.97	2.51	4.43	4.83	5.04	4.26	71.39
1901	11.72	3.96	6.22	6.27	3.98	1.85	3.79	8.64	5.08	2.50	1.10	8.38	63.49

OPELIKA, ALA.

Normal	5.64	5.13	5.28	3.78	3.14	4.33	5.32	4.44	2.64	2.98	3.11	5.09	50.88
1896	6.53	3.87	2.48	1.29	1.63	1.94	5.54	1.39	1.94	1.02	5.10	1.30	34.03
1897	1.25	5.92	9.09	5.37	1.03	.70	6.33	5.38	.96	2.14	3.29	3.33	44.79
1898	4.89	1.85	3.15	4.11	.11	1.26	6.39	9.30	3.43	9.27	7.26	7.66	58.68
1899	7.41	6.42	5.58	2.54	2.39	2.47	3.98	3.69	.31	2.78	1.75	5.96	45.28
1900	3.52	10.87	6.10	4.51	.07	9.89	4.64	4.05	6.16	8.29	7.80	7.17	73.07
1901	9.59	7.14	9.63	7.60	4.09	4.08	3.45	5.82	3.35	.50	1.25	10.88	67.38

OXANNA, ALA.

Normal	5.18	4.90	5.38	4.77	4.07	4.47	5.40	4.30	2.45	1.66	2.75	4.27	49.59
1896	4.13	3.76	3.76	2.64	2.72	4.10	4.25	.98	2.49	1.53	3.80	.66	34,56
1897	3.67	5.29	8.65	2.77	1.73	1.38	7.16	2.91	.00	.53	1.87	6.10	42.06
1898	3.00	.80	3.79	4.17	1.12	2.88	5.19	8.15	1.85	(1.66)	4.32	1.75	38.68
1899	4.36	6.42	5.93	2.99	1.30	2.05	8.81	3.66	.05	1.92	2.50	5.91	45.91
1900	3.95	8.80	5.52	8.99	2.29	10.86	6.41	1.56	4.69	3.52	5.24	3.99	65.82
1901	4.64	4.54	5.17	6.28	6.11	4.73	5.13	7.37	3.16	.70	1.44	8.40	57.67

TALLASSEE, ALA.

Normal	5.11	6.39	6.60	3.65	2.59	4.18	5.01	5.67	2.48	1.97	3.51	5.29	52.45
1896	(5.11)	6.40	5.55	2.72	4.39	(4.18)	(5.01)	(5.67)	(2.48)	(1.97)	(3.51)	1.30	48.29
1897	3.28	7.28	11.25	5.03	1.39	(4.18)	4.53	6.21	(2.48)	.41	1.92	4.11	52.12
1898	2.12	1.91	3.70	5.25	.25	3.71	7.23	7.40	1.35	(1.97)	7.12	(5.29)	47.30
1899	6.62	7.12	4.42	1.83	1.30	2.15	6.82	3.39	.24	3.79	2.17	4.79	44.64
1900	.78	8.84	6.07	5.55	1.58	6.48	(5.01)	4.06	3.20	2.57	4.30	5.55	53.99
1901	6.44	4.03	7.17	4.88	4.89	2.14	2.40	4.65	3.85	.82	1.87	12.77	55.91

WETUMKA, ALA.

Normal	4.80	5.13	5.39	4.41	3.23	3.37	5.19	4.75	2.07	2.94	3.14	4.78	49.20
1896	6.49	5.46	5.54	3.33	4.26	6.74	5.69	4.51	1.62	1.13	3.02	1.78	49.57
1897	2.92	5.81	14.02	5.46	.93	.86	2.04	6,73	1.78	.20	2.47	4.36	47.58
1898	2.12	2.15	3.03	6.05	.62	2.00	7.74	8.52	1.93	3.84	6.71	3.87	48.58
1899	6.95	6.15	3.92	2.08	2.76	2.75	6.39	2.41	.22	4.36	2.46	4.62	45.07
1900	3.12	9.30	5.97	6.54	1.88	6.96	2.71	5.52	5.26	7.73	5.13	6.42	66.54
1901	5.07	3.40	6.35	4.93	4.11	2.63	1.96	3.68	3.72	.97	1.44	8.96	47.22

The amount of water delivered from the drainage basin as measured at the points named below has been computed in terms of depth in inches. The normals given are the monthly averages for times during which measurements or computations were had. The figures for the yearly normal are the sums of these monthly averages.

Depth of run-off, in inches, from the drainage basin of Tallapoosa River at Milstead, Ala.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	1.96	2.78	2.50	2.60	1.13	1.28	1.22	1.38	.86	1.09	1.02	1.90	19.70
1898	.72	.52	.69	1.67	.45	.38	.75	2.22	.77	2.19	1.76	1.73	13.85
1899	2.53	4.26	3.72	2.62	1.00	.59	1.50	.67	.29	.30	.53	1.42	19.43
1900	1.12	3.50	3.07	2.62	1.12	2.42	1.63	.84	1.45	1.14	1.23	1.95	22.09
1901	3.45	2.83	2.52	3.49	1.94	1.74	1.01	1.78	.91	.71	.54	2.49	23.41

Rainfall and run-off in basin of Tallapoosa River.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Ashville	57.61	34.67	42.15	46.14	53.23	71.08	64.98
Goodwater	49.56	39.76	39.75	43.83	50.43	75.48	60.09
Lock No. 4	51.34	37.99	42.45	46.47	47.11	71.39	63.49
Opelika	50.88	34.03	44.79	58.68	45.28	73.07	67.38
Oxanna	49.59	34.56	42.06	38.68	45.91	65.82	57.67
Tallassee	52.45	48.29	52.12	47.30	44.64	53.99	55.91
Wetumka	49.20	49.57	47.58	48.58	45.07	66.54	47.22
Average	51.52	39.74	44.41	47.10	47.38	68.20	59.53
RUN-OFF.							
Tallapoosa at Milstead	19.70	.....	.....	13.85	19.43	22.09	23.41
Percentage of rainfall	38.24	.....	.....	29.41	41.01	32.39	39.32

COOSA RIVER.

Estimated monthly discharge of Etowah River at Canton, Ga.

[Drainage area, 604 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	14,185	988	1,965	3.25	3.75
February	5,470	1,154	2,135	3.53	3.68
March	14,600	988	1,890	3.13	3.61
April	4,474	1,154	2,290	3.81	4.25
May	14,268	1,154	2,394	3.96	4.57
June	4,889	1,154	2,442	4.04	4.51
July	2,648	905	1,317	2.18	2.51
August	11,280	820	2,533	4.19	4.83
September	2,814	988	1,483	2.46	2.74
October	2,897	590	1,039	1.72	1.98
November	1,320	905	1,052	1.74	1.94
December	17,090	988	2,715	4.50	5.19
The year	17,090	590	1,938	3.21	43.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 275; rating table on page 322 of same paper.

Estimated monthly discharge of Coosawattee River at Carters, Ga.

[Drainage area, 531 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	14,790	765	1,625	3.06	3.53
February	5,070	970	1,871	3.52	3.67
March	14,070	815	2,214	4.17	4.81
April	9,750	1,290	2,306	4.34	4.84
May	16,950	917	2,153	4.06	4.68
June	2,694	970	1,538	2.90	3.24
July	1,455	535	923	1.74	2.01
August	16,230	622	2,778	5.23	6.03
September	12,630	970	1,761	3.32	3.70
October	1,075	622	783	1.47	1.69
November	815	622	686	1.29	1.44
December	15,510	765	2,689	5.06	5.83
The year	16,950	535	1,777	3.35	45.47

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 277; rating table on page 322 of same paper.

Estimated monthly discharge of Oostanaula River at Resaca, Ga.[a]

[Drainage area, 1,614 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	22,274	1,700	6,222	3.86	4.45
February	12,522	1,880	4,655	2.88	3.00
March	21,446	1,700	5,597	3.47	4.00
April	16,846	2,870	6,699	4.15	4.63
November 13–30	.....	.....	1,211	.75	.50
December	22,182	1,000	5,958	3.69	4.25

[a] Half year station.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 278; rating table on page 322 of same paper.

Estimated monthly discharge at Coosa River at Rome, Ga.

[Drainage area, 4,006 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	52,930	4,600	15,450	3.86	4.45
February	35,845	4,900	12,186	3.04	3.17
March	52,930	4,600	13,406	3.34	3.85
April	36,046	6,901	15,578	3.88	4.33
May	51,724	4,150	12,533	3.12	3.60
June	19,966	4,450	8,316	2.08	2.32
July	9,715	2,850	4,441	1.10	1.27
August	45,292	2,850	13,780	3.44	3.97
September	21,172	3,120	6,389	1.59	1.77
October	5,230	2,350	3,414	.85	.98
November	2,850	2,110	2,316	.58	.65
December	64,186	2,475	13,428	3.35	3.86
The year	64,186	2,110	10,103	2.52	34.22

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 278; rating table on page 322 of same paper.

Estimated monthly discharge of Coosa River near Riverside, Ala.

[Drainage area, 7,065 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	55,900	8,970	26,089	3.69	4.25
February	41,100	8,970	21,784	3.08	3.21
March	56,700	7,400	20,613	2.92	3.37
April	51,100	14,500	30,616	4.33	4.83
May	40,700	6,670	16,195	2.29	2.64
June	26,100	6,810	12,335	1.75	1.95
July	10,300	4,900	6,535	.93	1.07
August	44,700	4,400	20,370	2.88	3.32
September	23,100	5,700	9,977	1.41	1.57
October	10,300	4,280	5,694	.81	.93
November	4,650	3,830	4,016	.57	.64
December	57,100	4,050	18,885	2.67	3.08
The year	57,100	3,830	16,092	2.28	30.86

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 279; rating table on page 322 of same paper.

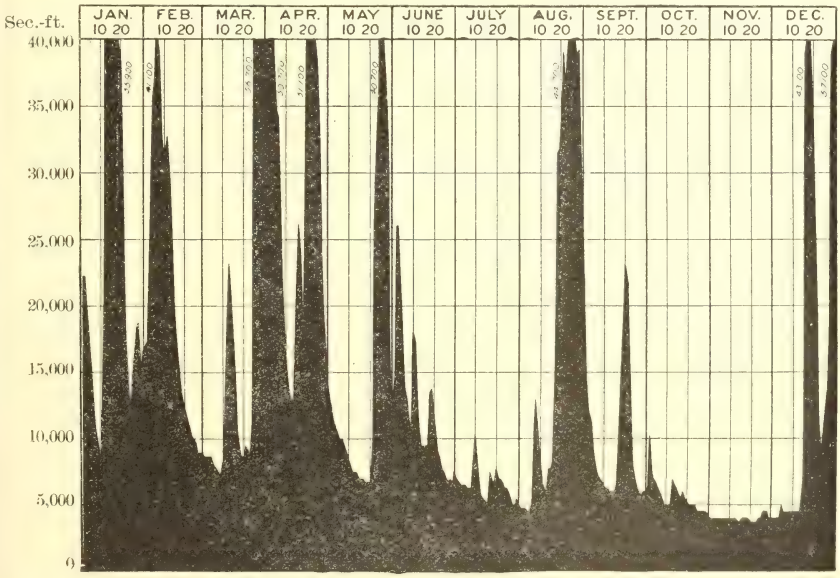


FIG. 29.—Discharge of Coosa River near Riverside, Ala., 1901.

Estimated monthly discharge of Talladega Creek at Nottingham, Ala.

[Drainage area, 156 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
August 16–31			113	0.72	0.43
September	2,286	74	575	3.69	4.12
October	636	90	190	1.22	1.41
November	724	130	249	1.60	1.79
December	746	152	291	1.87	2.16
1901.					
January	1,802	284	485	3.11	3.59
February	1,626	306	449	2.88	3.00
March	1,824	240	405	2.60	3.00
April	2,330	328	591	3.79	4.23
May	724	240	306	1.96	2.26
June	526	152	218	1.40	1.56
July	196	130	149	.96	1.11
August	372	90	148	.95	1.10
September	614	90	148	.95	1.06
October	482	90	123	.79	.91
November	152	90	97	.62	.69
December	1,714	90	264	1.69	1.95
The year	2,330	90	282	1.81	24.46

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 281; rating table on page 322 of same paper.

ALABAMA RIVER

Estimated monthly discharge of Alabama River at Selma, Ala.

[Drainage area, 13,500 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	50,110	9,676	26,495	1.96	2.26
February	128,540	10,920	63,763	4.72	4.91
March	89,478	37,874	58,272	4.32	4.98
April	109,960	21,648	60,909	4.51	5.03
May	41,864	13,668	21,090	1.56	1.80
June	94,000	12,220	35,288	2.61	2.91
July	93,468	12,660	33,964	2.52	2.90
August	38,140	9,124	14,156	1.05	1.21
September	52,504	7,189	17,366	1.29	1.44
October	35,480	7,097	14,492	1.07	1.23
November	46,120	7,596	18,506	1.37	1.53
December	48,780	8,750	28,989	2.15	2.48
The year	128,540	7,097	33,772	2.34	32.68
1901.					
January	107,300	22,446	61,213	4.53	5.22
February	95,862	30,692	55,037	4.08	4.25
March	92,670	21,382	39,017	2.89	3.33
April	104,640	32,288	73,048	5.41	6.04
May	59,420	10,120	26,966	2.00	2.31
June	53,568	7,818	26,030	1.93	2.15
July	21,318	7,596	13,536	1.00	1.15
August	66,868	9,532	30,853	2.29	2.64
September	46,120	10,428	19,394	1.44	1.61
October	21,914	7,931	11,022	.82	.95
November	8,750	7,931	8,266	.61	.68
December	94,000	8,511	26,638	1.97	2.27
The year	107,300	7,596	32,585	2.47	32.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 282; rating table on page 323 of same paper.

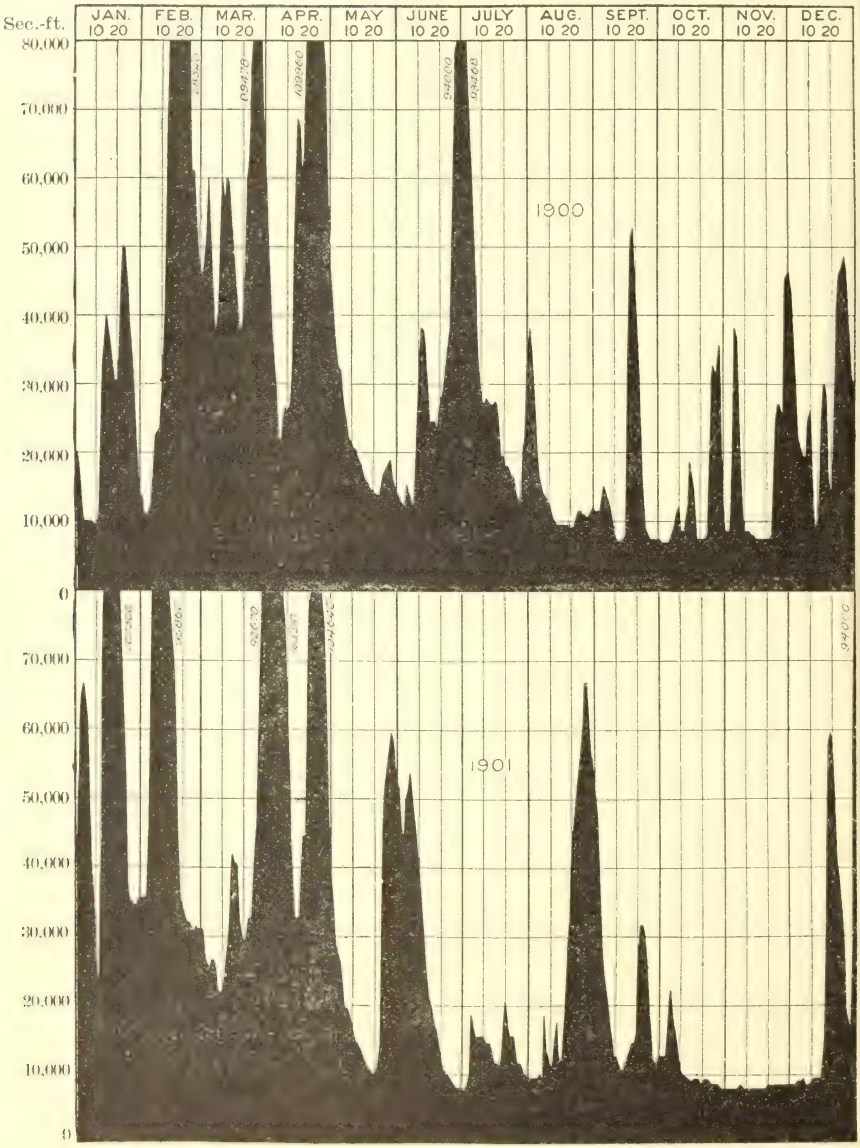


FIG. 30.—Discharge of Alabama River at Selma, Ala., 1900-1901.

BLACK WARRIOR RIVER.

Estimated monthly discharge of Mulberry Fork of Black Warrior River near Cordova, Ala.

[Drainage area, 1,900 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
June	49,284	1,134	16,185	8.52	9.51
July	11,248	810	2,975	1.57	1.81
August	2,144	660	1,016	.53	.61
September	1,951	205	556	.29	.32
October	13,098	60[a]	1,732	.91	1.05
November	6,808	384	1,487	.78	.87
December	6,660	968	2,154	1.13	1.30
1901.					
January	51,800	1,762	8,713	4.59	5.29
February	31,820	1,486	6,616	3.48	3.62
March	29,600	1,486	6,637	3.49	4.02
April	23,088	2,242	6,967	3.67	4.10
May	10,064	968	2,539	1.34	1.54
June	5,920	320	1,582	.83	.93
July	3,404	205	631	.33	.38
August	17,168	205	4,155	2.19	2.53
September	6,660	320	1,415	.74	.83
October	1,669	320	687	.36	.42
November	660	320	468	.25	.28
December	31,820	518	4,923	2.59	2.99
The year	51,800	205	3,778	1.99	26.93

[a] This minimum is estimated from rating curve. The lowest actual discharge measured was at gage height .40, and was 385 second-feet.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 283; rating table on page 323 of same paper.

Estimated monthly discharge of Black Warrior River at Tuscaloosa, Ala.

[Drainage area, 4,900 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	108,375	4,370	22,938	4.68	5.39
February	55,100	4,165	15,094	3.08	3.21
March	40,900	3,815	11,947	2.44	2.81
April	57,020	5,330	17,370	3.55	3.96
May	10,765	2,330	4,355	.89	1.03
June	9,010	850	3,217	.66	.74
July	3,815	415	1,210	.25	.29
August	29,550	340	7,117	1.45	1.67
September	8,660	710	2,626	.54	.60
October	4,775	445	1,536	.31	.36
November	1,022	512	712	.15	.17
December	80,250	710	13,293	2.71	3.12
The year	108,375	340	8,454	1.73	23.35

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 284; rating table on page 323 of same paper.

TOMBIGBEE RIVER.

Estimated monthly discharge of Tombigbee River at Columbus, Miss.

[Drainage area, 4,440 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	13,864	2,962	5,588	1.26	1.45
February	16,486	2,686	8,659	1.95	2.03
March	23,938	6,688	15,285	3.42	3.85
April	40,498	3,100	21,265	4.79	5.34
May	13,450	1,464	4,944	1.11	1.28
June	37,600	3,790	27,692	6.24	6.96
July	29,596	2,410	11,411	2.57	2.97
August	10,414	707	2,257	.51	.59
September	1,775	632	950	.21	.23
October	10,138	566	3,989	.90	1.04
November	10,000	1,097	4,304	.97	1.08
December	11,794	1,464	5,239	1.18	1.36
The year	40,498	566	9,299	2.09	28.18
1901.					
January	33,736	2,410	14,193	3.20	3.69
February	24,352	3,790	12,533	2.83	2.95
March	29,182	3,514	10,884	2.45	2.83
April	21,040	3,376	9,890	2.23	2.49
May	11,656	1,328	4,949	1.11	1.28
June	7,792	707	2,767	.62	.69
July	1,097	582	730	.16	.18
August	24,352	582	7,673	1.73	1.99
September	7,240	753	2,008	.45	.50
October	915	650	748	.17	.20
November	1,000	650	756	.17	.19
December	17,590	810	6,730	1.52	1.75
The year	33,736	582	6,155	1.39	18.74

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 285; rating table on page 323 of same paper.

Estimated monthly discharge of Tombigbee River at Epes, Ala.

[Drainage area, 8,830 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	47,100	3,878	25,579	2.90	3.34
February	35,700	6,350	20,999	2.38	2.48
March	30,300	6,350	16,198	1.83	2.11
April	34,500	6,350	18,102	2.05	2.29
May	12,900	3,002	6,880	.78	.90
June	12,900	1,484	4,585	.52	.58
July	1,484	810	1,295	.15	.17
August 16–31	.....	.....	21,541	2.44	1.41
September	7,500	1,484	2,205	.36	.40
October	5,820	1,164	1,633	.18	.21
November	2,200	880	1,550	.18	.20
December	30,900	1,960	12,249	1.39	1.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 286; rating table on page 323 of same paper.

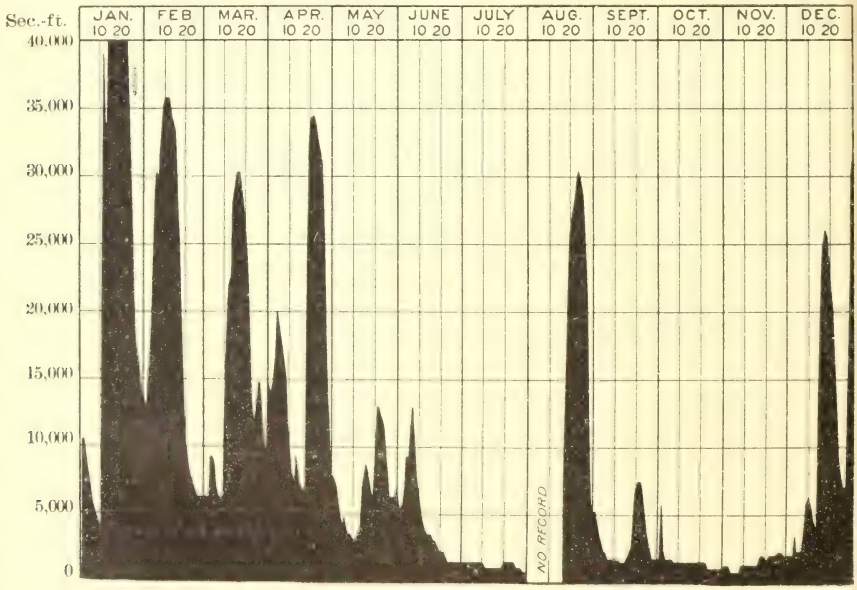


FIG. 31.—Discharge of Tombigbee River at Epes, Ala., 1901.

EASTERN MISSISSIPPI RIVER DRAINAGE.

For convenience of classification the tributaries of the Mississippi River draining from the east and including the main river above its junction with the Missouri, have here been grouped together. These eastern tributaries vary widely in character, both as regards type of rivers and the topography of the areas which they drain. Those draining the comparatively low rolling country adjacent to the valley of the Mississippi are as a rule sluggish streams with few falls of importance, while the upper Ohio River and its numerous tributaries, on the contrary, drain a country of high elevations, their upper courses being through narrow V-shaped valleys, with frequent falls and with high rocky banks. Owing to the steep slopes the run-off is rapid, causing sudden fluctuations in the streams and giving rise to the high floods and extreme low waters for which the Ohio Basin is noted, and the influence of which is felt to a marked degree even in the flow of Mississippi River below Cairo.

Systematic records have been kept during 1901 at numerous points along the principal tributaries of the Ohio River, on the Mississippi River at St. Paul, and on the Yazoo River at Yazoo City.

UPPER OHIO RIVER.

Estimated monthly discharge of Youghiogheny River at Friendsville, Md.

[Drainage area, 295 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	1,942	575	803	2.72	3.14
February	600	600	600	2.03	2.11
March	4,450	600	1,824	6.18	7.12
April	4,336	865	2,103	7.13	7.96
May	3,082	400	1,167	3.96	4.57
June	1,942	300	692	2.35	2.62
July	785	130	231	.78	.90
August	400	130	194	.66	.76
September	300	95	159	.54	.60
October	130	95	105	.36	.42
November	350	95	176	.60	.67
December	5,362	300	1,651	.56	.65
The year	5,362	95	809	2.32	31.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 289; rating table on page 323 of same paper.

Estimated monthly discharge of Cheat River near Uneva, W. Va.

[Drainage area 1,375 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1899.					
July	.....	.....	1,370	1.00	1.00
August	2,232	357	924	.67	.77
September	3,210	404	952	.69	.77
October	465	273	336	.24	.28
November	3,070	538	1,732	1.26	1.41
December	6,442	1,000	2,387	1.74	2.01
1900.					
July	4,610	730	1,888	1.37	1.58
August	1,956	273	614	.45	.52
September	730	190	254	.18	.20
October	730	190	340	.25	.29
November	3,070	273	903	.66	.59
December	7,270	1,136	2,682	1.95	2.03

NOTE.—Gage heights and discharge measurements have been published as follows: For 1899, in Water-Supply Paper No. 36, page 160; for 1900, in Water-Supply Paper No. 48, page 177; rating table in Water-Supply Paper No. 65, page 323; later measurements on page 290 of same paper.

GREAT KANAWHA RIVER.

Estimated monthly discharge of Greenbrier River at Alderson, W. Va.

[Drainage area, 1,344 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	21,050	590	2,339	1.74	2.01
February	2,440	590	1,031	.77	.80
March	14,300	590	2,685	2.00	2.31
April	19,340	1,535	6,320	4.70	5.24
May	20,875	857	4,349	3.24	3.74
June	20,530	920	3,938	2.93	3.27
July	4,080	280	1,277	.95	1.10
August	2,550	250	845	.63	.73
September	2,110	280	689	.51	.57
October	315	145	230	.17	.20
November	425	120	188	.14	.16
December	37,700	250	4,765	3.55	4.10
The year	37,700	120	2,388	1.78	24.23

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 290; rating table on page 323 of same paper.

Estimated monthly discharge of New River at Radford, Va.

[Drainage area, 2,725 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1898.					
August	16,080	2,220	4,257	1.56	1.80
September	31,160	1,800	5,587	2.05	2.29
October	49,880	2,450	9,068	3.33	3.84
November	4,765	2,450	3,475	1.28	1.43
December	11,920	2,970	4,806	1.76	2.03
1899.					
January	19,200	3,250	5,595	2.05	2.36
February	28,040	2,970	12,521	4.60	4.79
March	53,000	7,240	18,126	6.65	7.68
April	19,720	3,860	8,493	3.12	3.48
May	9,320	2,970	5,390	1.98	2.28
June	18,680	2,000	4,307	1.58	1.76
July	3,860	1,400	2,043	.75	.86
August	4,290	1,400	1,968	.72	.83
September	6,720	1,400	2,513	.92	1.03
October	2,000	1,400	1,452	.53	.61
November	3,860	950	1,645	.60	.67
December	20,240	950	3,165	1.16	1.34
The year	53,000	950	5,602	2.06	27.69
1900.					
January	14,000	1,800	4,173	1.53	1.76
February	23,360	2,000	6,802	2.50	2.60
March	32,720	3,860	11,244	4.13	4.76
April	19,200	2,970	6,656	2.44	2.72
May	8,800	3,250	4,156	1.53	1.76
June	8,800	2,970	4,824	1.77	1.97
July	9,840	1,400	2,635	.97	1.12
August	2,220	575	1,209	.44	.51
September	13,220	600	2,239	.82	.91
October	118,000	850	7,810	2.87	3.31
November	38,960	2,000	5,371	1.97	2.20
December	21,800	2,700	5,315	1.95	2.25
The year	118,000	575	5,203	1.91	25.87

Estimated monthly discharge of New River at Radford, Va.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	22,320	2,220	4,325	1.59	1.83
February	6,200	1,600	3,155	1.16	1.21
March	24,400	675	4,587	1.68	1.94
April	128,400	3,540	16,214	5.95	6.64
May	137,760	3,860	16,651	6.11	7.05
June	42,080	5,715	14,807	5.43	6.06
July	34,800	3,860	8,997	3.30	3.80
August	106,560	3,540	21,850	8.02	9.24
September	32,200	3,540	8,264	3.03	3.38
October	14,000	2,220	4,604	1.69	1.95
November	4,765	1,400	2,092	.77	.86
December	99,800	1,600	15,605	5.73	6.60
The year	137,760	675	10,096	3.71	50.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 293; rating table on page 323 of same paper.

Estimated monthly discharge of New River at Fayette, W. Va.

[Drainage area, 6,200 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	29,100	5,520	11,220	1.81	2.09
February	12,350	5,520	8,036	1.30	1.35
March	32,400	5,520	12,775	2.06	2.38
April [a]	107,740	14,946	41,855	6.75	7.53
May 1–22 [a]	60,430	11,100	17,700	2.85	2.33

[a] Approximate from Apr. 21 to May 4.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 294.

TENNESSEE RIVER.

Estimated monthly discharge of French Broad River near Asheville, N. C.

[Drainage area, 987 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	12,940	2,170	3,206	3.25	3.75
February	4,135	2,055	2,396	2.42	2.51
March	22,220	1,945	4,166	4.22	4.86
April	15,655	3,145	6,772	6.86	7.65
May	24,160	2,620	5,043	5.11	5.89
June	10,800	3,060	4,852	4.92	5.49
July [a]					
August	20,320	2,000	10,740	10.88	12.54
September	11,500	2,760	5,132	5.20	5.80
October	7,300	2,170	2,810	2.84	3.28
November	2,170	1,890	1,984	2.01	2.24
December	26,350	1,890	6,288	6.37	7.35

[a] No record.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 301; rating table on page 323 of same paper.

Estimated monthly discharge of Tennessee River at Knoxville, Tenn.

[Drainage area, 8,990 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1900.					
January	19,322	3,850	8,717	0.97	1.12
February	56,505	4,850	18,202	2.02	2.10
March	58,830	15,818	28,349	3.15	3.64
April	27,210	11,082	14,942	1.66	1.85
May	11,082	6,170	8,179	.91	1.05
June	33,720	5,882	12,860	1.43	1.60
July	25,350	5,322	9,867	1.10	1.27
August	11,082	4,250	5,697	.63	.73
September	14,570	3,450	5,722	.64	.71
October	41,160	3,450	7,568	.84	.97
November	42,090	4,850	10,282	1.14	1.27
December	28,140	6,462	10,814	1.20	1.38
The year	58,830	3,450	11,767	1.31	17.69

Estimated monthly discharge of Tennessee River at Knoxville, Tenn.—Continued.

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	60,225	7,062	17,154	1.91	2.20
February	18,822	6,760	12,202	1.36	1.42
March	71,850	6,760	16,188	1.80	2.08
April	76,965	16,242	37,089	4.13	4.61
May	146,250	10,010	30,837	3.43	3.96
June	44,880	13,362	23,340	2.60	2.90
July	20,237	6,760	11,622	1.29	1.49
August	77,430	6,760	34,046	3.79	4.37
September	36,510	8,322	15,342	1.71	1.91
October	15,398	6,170	8,546	.95	1.10
November	6,760	5,050	5,698	.63	.70
December	141,600	5,322	30,796	3.43	3.95
The year	146,250	5,050	20,238	2.25	30.69

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 303; rating table on page 324 of same paper.

Estimated monthly discharge of Tuckasegee River at Bryson, N. C.

[Drainage area, 662 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	19,580	1,015	2,432	3.67	4.23
February	3,675	950	1,538	2.32	2.41
March	17,550	950	2,862	4.32	4.98
April	11,125	2,255	3,828	5.78	6.45
May	26,250	1,370	3,536	5.34	6.15
June	3,675	1,700	2,255	3.41	3.81
July	2,850	830	1,250	1.89	2.18
August	19,000	710	4,653	7.03	8.10
September	5,515	1,295	2,003	3.02	3.37
October	2,650	830	1,034	1.56	1.80
November	950	600	707	1.07	1.19
December	35,820	600	4,285	6.47	7.46
The year	35,820	600	2,532	3.82	52.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 304; rating table on page 324 of same paper.

A. GREENBRIER RIVER NEAR WHITE SULPHUR SPRINGS, W. VA.

B. GAGING STATION ON TENNESSEE RIVER AT CHATTANOOGA, TENN.

Estimated monthly discharge of Little Tennessee River at Judson, N. C.

[Drainage area, 675 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	13,800	1,250	2,349	3.48	4.01
February	2,955	1,250	1,642	2.43	2.53
March	23,650	1,185	2,277	4.86	5.60
April	14,000	1,725	3,987	5.91	6.59
May	40,580	1,250	3,762	5.57	6.43
June	7,560	1,435	2,740	4.06	4.53
July	3,510	1,125	1,745	2.59	2.99
August	22,125	1,125	6,183	9.16	10.56
September	3,140	1,250	1,550	2.30	2.57
October	3,525	1,125	1,374	2.04	2.36
November	1,125	785	909	1.35	1.51
December	57,540	735	8,120	12.00	13.83
The year	57,540	735	3,136	4.65	63.51

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 305; rating table on page 324 of same paper.

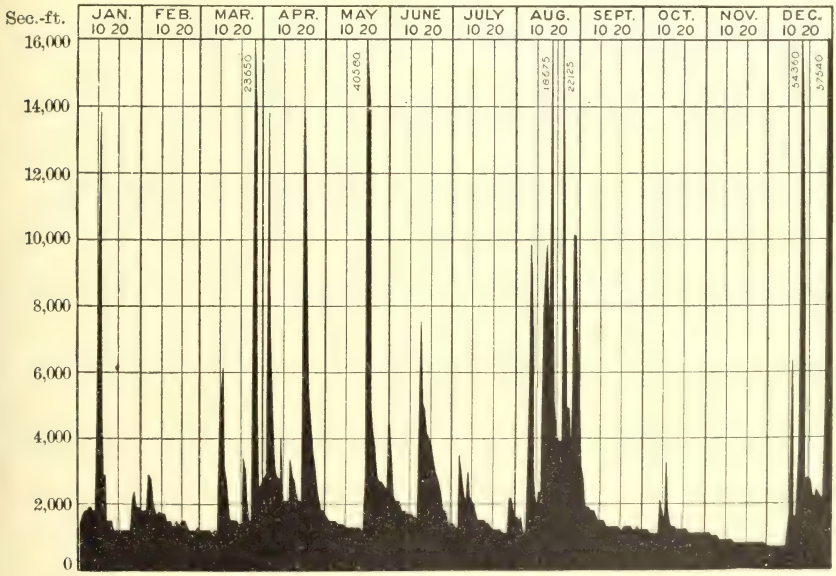


FIG. 32.—Discharge of Little Tennessee River at Judson, N. C., 1901.

Estimated monthly discharge of Hiwassee River at Murphy, N. C.

[Drainage area, 410 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	6,960	670	1,599	3.90	4.50
February	3,990	750	1,429	3.49	3.63
March	9,840	710	1,554	3.79	4.37
April	10,920	1,380	2,535	6.18	6.89
May	9,480	750	1,941	4.73	5.45
June	2,100	840	1,265	3.09	3.45
July	3,180	520	829	2.02	2.33
August	13,260	450	3,068	7.48	8.62
September	3,360	750	1,254	3.06	3.42
October	1,560	485	627	1.53	1.76
November	630	420	484	1.18	1.32
December	14,340	450	1,976	4.82	5.55
The year	14,340	420	1,547	3.77	51.29

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 306; rating table on page 324 of same paper.

Estimated monthly discharge of Nottely River at Ranger, N. C.

[Drainage area, 272 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
February 16–28			514	1.89	0.91
March	3,410	440	774	2.85	3.29
April	2,000	620	956	3.51	3.92
May	3,860	410	894	3.29	3.79
June	1,460	530	790	2.90	3.24
July	2,300	380	639	2.35	2.71
August	4,100	290	1,486	5.46	6.29
September	2,660	530	823	3.03	3.38
October	590	350	463	1.70	1.96
November	560	350	386	1.42	1.58
December	5,360	380	927	3.41	3.93

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 308; rating table on page 324 of same paper.

Estimated monthly discharge of Hiwassee River at Reliance, Tenn.

[Drainage area, 1,180 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	30,800	1,805	5,015	4.25	4.91
February	12,560	1,485	3,448	2.92	3.04
March	34,640	1,805	4,595	3.89	4.49
April	25,040	3,350	6,282	5.32	5.93
May	37,520	2,170	5,468	4.63	5.35
June	7,250	2,375	3,576	3.03	3.38
July	3,620	1,485	2,116	1.79	2.06
August	33,680	1,340	8,190	6.94	8.00
September	5,790	2,375	3,348	2.84	3.17
October	2,375	1,340	1,796	1.52	1.75
November	1,805	1,340	1,494	1.27	1.42
December	32,240	1,340	6,257	5.30	6.12
The year	37,520	1,340	4,299	3.68	49.62

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 308; rating table on page 324 of same paper.

Estimated monthly discharge of Hiwassee River at Charleston, Tenn.

[Drainage area, 2,297 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	34,000	3,550	7,774	3.38	3.90
February	13,845	3,695	5,860	2.55	2.66
March	29,505	3,550	7,549	3.28	3.79
April	28,780	5,725	10,384	4.51	5.03
May	35,740	3,985	8,999	3.91	4.51
June	12,540	4,275	6,329	2.75	3.07
July	6,595	2,825	3,789	1.65	1.90
August	25,735	2,390	11,052	4.81	5.55
September	16,165	3,840	5,624	2.45	2.73
October	5,290	2,825	3,340	1.45	1.67
November	3,405	2,390	2,709	1.18	1.32
December	37,190	2,390	8,840	3.84	4.43
The year	37,190	2,390	6,854	2.98	40.56

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 309; rating table on page 324 of same Paper.

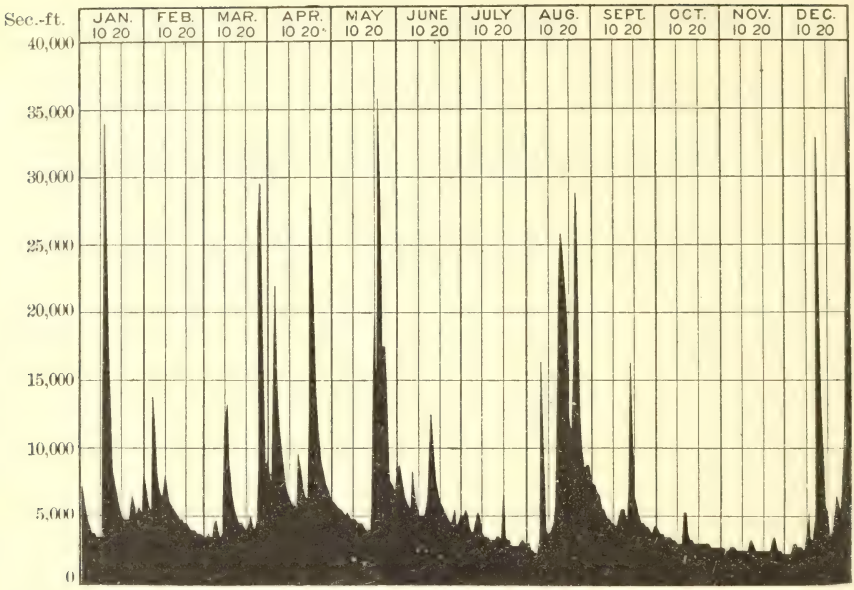


FIG. 33.—Discharge of Hiwassee River at Charleston, Tenn., 1901.

Estimated monthly discharge of Toccoa River, near Blueridge, Ga.

[Drainage area, 231 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	5,228	552	1,100	4.76	5.49
February	1,590	552	765	3.31	3.44
March	4,800	666	1,077	4.66	5.37
April	3,195	1,062	1,458	6.31	7.04
May	9,080	666	1,599	6.92	7.98
June	1,590	666	1,011	4.38	4.88
July	1,590	666	768	3.32	3.82
August	12,290	666	2,248	9.73	11.22
September	1,590	666	1,144	4.95	5.52
October	804	552	619	2.68	3.09
November	552	460	493	2.13	2.38
December	10,150	552	2,248	9.73	11.22
The year	12,290	460	1,211	5.24	71.45

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 310; rating table on page 324 of same Paper.

Estimated monthly discharge of Tennessee River at Chattanooga, Tenn.

[Drainage area, 21,418 square miles.]

Month.	Discharge in second-feet.			Run-off.	
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.
1901.					
January	189,200	19,600	50,641	2.36	2.72
February	59,850	19,050	36,516	1.70	1.77
March	139,150	19,050	44,952	2.10	2.42
April	166,450	38,400	95,080	4.44	4.95
May	205,450	26,380	68,736	3.21	3.70
June	72,200	33,850	47,673	2.23	2.49
July	37,100	14,680	23,932	1.12	1.29
August	207,400	13,800	75,761	3.54	4.08
September	61,150	22,660	38,859	1.81	2.02
October	25,760	13,360	18,979	.89	1.03
November	13,800	11,660	13,076	.61	.68
December	237,300	12,080	65,509	3.06	3.53
The year	237,300	11,660	48,310	2.26	30.68

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 311; rating table on page 324 of same Paper.

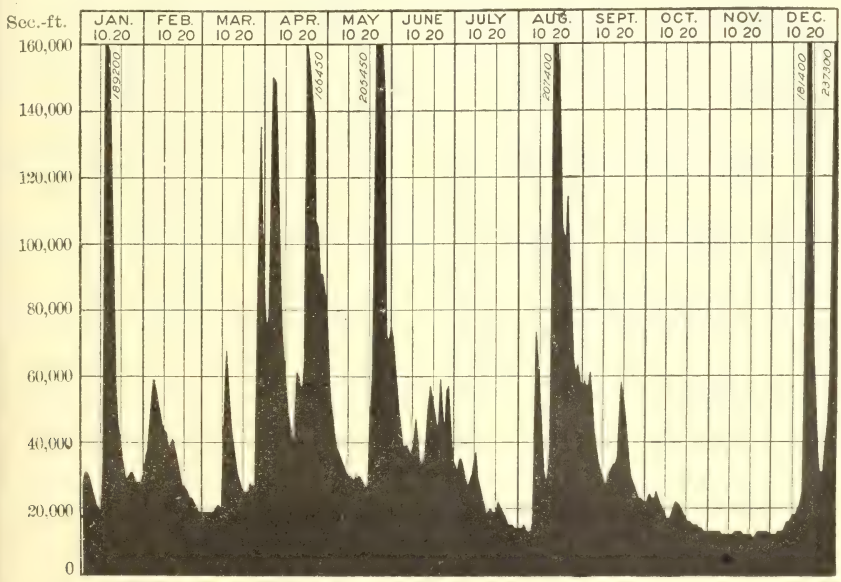


FIG. 34.—Discharge of Tennessee River at Chattanooga, Tenn., 1901.

GREAT LAKES DRAINAGE.

Stations have been maintained, as in past years, on Sandusky River at Fremont, Ohio, and on Maumee River near Waterville, Ohio, but owing to lack of sufficient discharge measurements the flow of the former during 1901 has not been computed. Stations were maintained during 1901 on Grand River at North Lansing, Mich., and at several points in the city of Grand Rapids, Mich. Results of measurements made of Grand River at the Chicago and West Michigan Railroad bridge at Grand Rapids, Mich., are given for the years 1897 to 1900, the records of daily discharge of which were published in Water-Supply Paper No. 49, page 243.

MAUMEE RIVER.

In the following pages are given the results of measurements made during 1901 for Maumee River at Waterville, Ohio, together with a comparison of the run-off from the drainage basin with the precipitation observed at the rainfall stations in the basin.

Estimated monthly discharge of Maumee River near Waterville, Ohio.

[Drainage area, 6,111 square miles.]

Month.	Discharge in second-feet.			Run-off.			Rainfall.
	Maximum.	Minimum.	Mean.	Second-feet per square mile.	Depth in inches.	Per cent of rainfall.	
1901.							*Inches.*
January	6,110	480	2,389	0.391	0.451	23.7	1.90
February	9,450	580	3,716	.608	.633	43.6	1.45
March	27,600	2,240	11,207	1.834	2.114	81.9	2.58
April	8,160	1,020	3,646	.596	.658	30.2	2.18
May	22,750	530	3,147	.515	.594	15.3	3.90
June	15,220	660	3,599	.589	.657	17.1	3.84
July	14,215	80	2,503	.410	.473	15.5	3.06
August	140	5	47	.008	.009	.3	2.74
September	80	10	42	.007	.008	.6	1.35
October	1,020	10	246	.040	.046	1.7	2.73
November	180	60	98	.016	.018	1.2	1.53
December	11,200	110	2,585	.423	.488	13.5	3.63
The year	27,600	5	2,771	.453	6.149	19.9	30.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 65, page 313

PRECIPITATION IN BASIN OF MAUMEE RIVER.

The principal observations of rainfall made within the basin of Maumee River are at the stations enumerated in the following table, which gives the precipitation by months for 1901. The figures of

average monthly precipitation derived from this table are compared in the next preceding table with the monthly discharge of Maumee River near Waterville, showing the relation between precipitation and run-off in the basin.

Precipitation at stations in drainage basin of Maumee River.

Station.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1901.													
Angola	3.19	1.93	3.26	2.54	2.75	4.10	5.95	4.58	0.87	6.15	1.81	3.47	40.60
Auburn	1.58	1.44	1.15	1.94	2.45	2.87	1.38	3.71	1.30	3.71	1.15	1.57	24.25
Bluffton	1.17	.93	2.76	2.34	4.16	3.29	1.23	4.79	1.12	3.40	1.50	4.01	30.70
Fort Wayne	1.49	1.74	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Adrian	2.12	1.31	2.37	1.33	2.53	2.23	1.75	2.05	.97	3.46	1.89	2.91	24.92
Coldwater	2.79	1.75	2.71	2.18	1.78	4.96	4.67	4.10	.73	6.56	1.82	3.25	37.30
Hillsdale	2.53	2.63	2.95	1.98	2.64	3.55	2.68	2.20	.93	5.63	2.00	3.12	32.84
Benton Ridge	1.42	2.10	3.15	2.03	3.70	3.59	2.66	2.02	1.82	.24	.....	3.59	.....
Bowling Green	2.57	1.30	2.86	2.23	4.91	3.98	4.42	4.38	1.32	1.15	2.33	4.21	35.66
Celina	1.74	.80	3.14	2.27	4.79	3.98	3.24	1.86	1.95	.94	.95	3.58	29.24
Defiance	1.10	1.07	2.35	1.87	3.93	3.47	6.08	2.16	1.54	2.63	1.41	4.14	31.75
Findlay	1.46	1.45	3.30	2.46	4.65	2.79	1.36	2.96	1.85	.86	.94	3.87	37.95
Hedges	1.12	1.03	3.02	2.19	5.28	3.26	1.89	2.25	1.76	2.27	1.35	4.03	29.45
Kenton	2.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
Leipsic	1.33	1.70	2.20	1.81	3.95	3.95	3.20	2.14	.....	1.22	1.01	4.43	.....
Montpelier	3.30	1.70	2.44	2.82	3.52	4.01	5.07	2.45	.92	4.09	1.71	3.10	35.03
Napoleon	1.58	1.25	2.51	2.01	4.03	5.10	2.98	2.53	.64	1.73	1.27	3.02	28.65
New Bremen	1.28	.77	1.26	2.11	4.67	5.14	1.68	2.11	1.44	1.09	1.25	3.75	26.55
Ottawa	1.64	1.26	2.60	2.34	4.32	2.46	3.32	2.61	1.61	.59	1.64	2.25	27.64
Swanton	2.01	1.44	2.05	2.12	3.58	6.68	3.71	2.55	1.32	1.36	1.92	3.88	32.62
Van Wert	1.68	1.46	2.04	2.11	6.63	2.32	1.63	1.50	1.74	2.24	1.28	4.64	29.27
Wauseon	2.10	1.38	3.57	2.99	3.67	5.15	2.36	1.93	1.95	2.88	1.61	5.73	35.32
Total	41.81	30.44	51.69	43.67	77.94	76.88	61.26	54.88	25.68	51.96	29.14	72.55	.....
Mean	1.90	1.45	2.58	2.18	3.90	3.84	3.06	2.74	1.35	2.73	1.53	3.63	30.89

GRAND RIVER.

Estimated monthly discharge of Grand River at the Chicago and West Michigan Railroad bridge, Grand Rapids, Mich.

[Drainage area, 4,900 square miles.]

Month.	Mean discharge in second-feet.	Run-off	
		Second-feet per square mile.	Depth in inches.
1897.			
May	2,892	0.59	0.68
June	1,761	.36	.40
July	1,582	.33	.38
August	1,517	.31	.36
September	1,370	.28	.31
October	1,181	.24	.28

Estimated monthly discharge of Grand River at the Chicago and West Michigan Railroad bridge, Grand Rapids, Mich.—Continued.

Month.	Mean discharge in second-feet.	Run-off	
		Second-feet per square mile.	Depth in inches.
1897.			
November	1,483	0.30	0.33
December	2,382	.49	.56
1898.			
January	3,007	.61	.70
February	7,240	1.48	1.54
April	4,933	1.01	1.13
May	2,365	.48	.55
June	1,735	.35	.39
July	1,487	.30	.35
August	1,867	.38	.44
September	1,694	.35	.39
October	1,833	.37	.43
November	2,645	.54	.60
December	3,024	.62	.71
1899.			
January	6,965	1.42	1.64
February	4,723	.96	1.00
March	9,643	1.97	2.27
April	10,708	2.18	2.43
May	3,088	.63	.72
June	2,236	.46	.52
July	1,719	.35	.40
August	1,617	.33	.38
September	1,741	.36	.40
October	1,715	.35	.40
November	1,798	.37	.41
December	2,059	.42	.48
The year	4,001	.82	11.05
1900.			
January	2,620	.53	.61
February	7,524	1.53	1.59
March	5,945	1.21	1.39
April	11,991	2.45	2.73

HUDSON BAY DRAINAGE.

During the year 1901 systematic measurements were commenced in the basin of Red River of the North within the United States, under the direction of Prof. Charles M. Hall, director of the State agricultural and economic survey of North Dakota. Red River has its source in Lake Traverse and in its course through the United States forms the boundary between the States of Minnesota and North and South Dakota, draining a broad level area of highly fertile lands. After crossing the international boundary it receives from the west Mouse River, a tributary of considerable length, which drains a large area of North Dakota; it then flows into Lake Winnipeg, whence, after mingling with the waters of the Saskatchewan, it discharges through Nelson River into Hudson Bay.

Stations were maintained during 1901 on Red River at Grand Forks, N. Dak., Moorhead, Minn., and Pembina, N. Dak., and on Red Lake River at Crookston, Minn., with a view to studying the feasibility of irrigating lands in Red River Valley. No results of measurements for 1901 are here published, however, the data being insufficient for the present to warrant computation of the flow at these points.

ST. MARY RIVER.

In connection with the contemplated water storage and diversion of St. Mary River into Milk River, a station was established during 1901 on St. Mary River at Main, Mont. The river is a tributary of Belly River, which in its turn flows into the Saskatchewan. A full description of St. Mary River was published in the Twenty-second Annual Report, Part IV, pages 268 to 271, and additional information is set forth in the following pages, relating to the diversion scheme alluded to.

Estimated monthly discharge of St. Mary River at Main, Mont.

[Drainage area, 298 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
July 14–31			1,906	68,049	6.40	4.29
August	1,574	653	932	57,306	3.13	3.61
September	677	485	576	34,274	1.93	2.15
October	465	326	401	24,657	1.35	1.56
November	345	265	292	17,375	.98	1.09
December	278	220	241	14,819	.80	.92

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 15; rating table on page 170 of same paper.

UPPER MISSOURI RIVER DRAINAGE.

The Missouri is formed by the junction in southeastern Montana, at Three Forks, of Jefferson, Madison, and Gallatin rivers. Its principal tributaries are the Milk and Yellowstone, which for convenience are considered separately. Discharge measurements are in progress on all of these streams, as well as on Crow Creek, a tributary of Missouri River, and on the Upper Missouri proper at Townsend, Mont., where the Missouri River Commission maintains a gage. Results for 1901 are given in the following pages.

PRECIPITATION IN UPPER BASIN OF MISSOURI RIVER.

The principal observations of rainfall made within the basin of the headwaters of Missouri River are at the stations enumerated in the

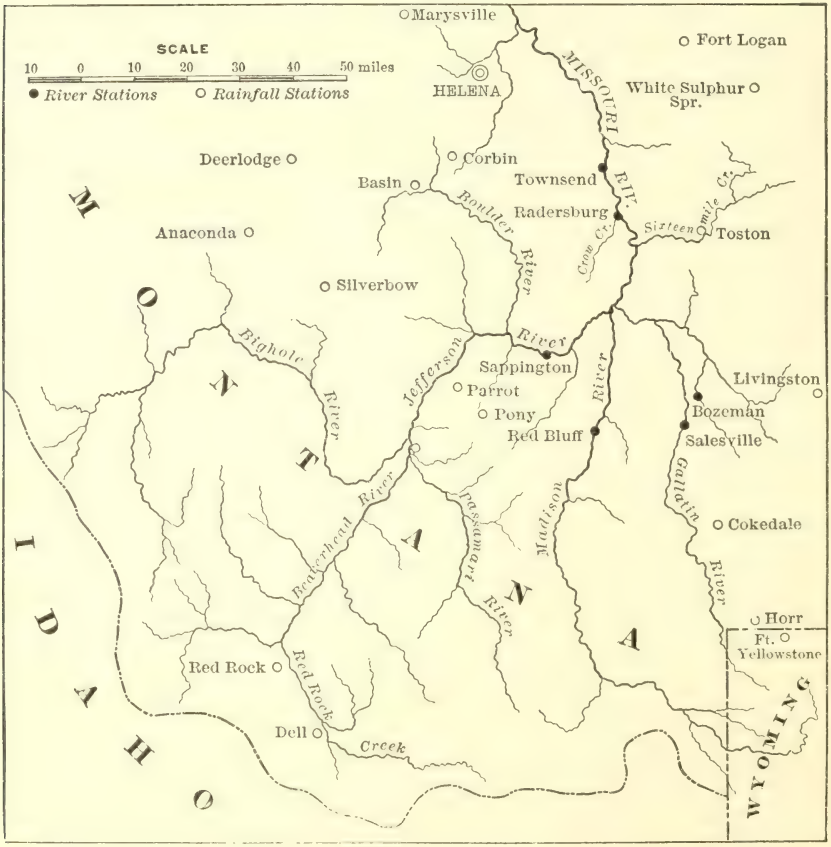


FIG. 35.—Location of river and rainfall stations in the upper basin of Missouri River.

following table, which also gives their geographic location, elevation above sea level, and length of record of observations. The relative location of these points is shown in fig. 35, in connection with the points of river measurement which are located at Salesville, Logan, Redbluff, Sappington, Bozeman, Radersburg, and Townsend.

Location of rainfall stations in Upper Missouri River Basin.

Station.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Butte	Silverbow	Montana				7- 8
Fort Logan	Meagher	do				11-13
Fort Yellowstone.	Yellowstone National Park.	Wyoming	44 58	110 41	6,370	13-16
Helena	Lewis and Clarke	Montana	46 34	112 4		21-22
Livingston	Park	do			4,487	5- 7

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation by months for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation, the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of Upper Missouri River.

BUTTE, MONT.

Year.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	6.05	0.69	1.04	1.32	1.95	1.62	1.05	0.73	1.16	0.94	0.56	0.77	17.88
1896	.30	.37	.32	.55	1.43	1.07	1.19	.87	1.95	.47	1.62	.37	10.51
1897	1.20	.70	1.04	1.63	1.44	3.02	1.19	.30	.98	1.10	1.52	1.12	15.24
1898	.57	.55	1.56	.51	(1.95)	3.06	.54	.45	.91	(.94)	(.56)	(.77)	12.37
1899	2.35	1.39	1.21	1.57	2.46	.55	.90	2.35	.55	1.65	.14	1.10	16.22
1900	.30	1.05	1.20	2.75	2.90	.66	1.13	.48	1.40	2.08	.20	.40	14.55
1901	.60	.65	1.65	2.35	3.40	2.00	.55	.30	.90	.45	T.	1.70	14.55

FORT LOGAN, MONT.

Normal	0.61	0.48	0.79	1.04	1.89	2.25	0.95	0.60	1.08	0.86	0.89	0.70	12.14
1896	(.61)	.02	.19	.26	1.48	.62	2.90	(.60)	(1.08)	.44	2.71	(.70)	11.61
1897	.62	.62	.74	.82	1.22	3.98	2.21	T.	.48	1.96	2.59	(.70)	15.94
1898	.09	.00	1.68	.66	4.48	3.23	1.76	.49	.40	1.23	2.04	.56	16.62
1899	1.26	.40	.64	.42	.67	(2.25)	T.	1.00	.30	1.71	.10	.82	9.57
1900	T.	.54	.79	1.33	1.61	.67	.15	.49	1.31	1.18	.36	.34	8.77
1901	.72	1.50	.72	1.71	(1.89)	3.59	.70	.85	2.43	.11	T.	1.50	15.72

FORT YELLOWSTONE, WYO.

Normal	2.51	2.15	2.23	1.45	1.91	1.62	1.20	1.15	1.02	1.26	2.20	2.32	21.02
1896	2.21	2.07	2.62	1.29	3.85	.73	2.09	.37	1.10	.06	3.92	.46	20.77
1897	1.12	.83	1.08	1.21	1.55	2.34	1.11	.57	.31	1.72	2.98	.80	15.62
1898	.31	1.21	1.40	.95	1.95	2.67	1.15	2.05	.90	2.25	1.55	.67	17.06
1899	4.21	3.40	3.00	2.30	2.52	1.90	1.42	2.23	.90	2.02	.04	1.90	25.84
1900	.92	1.65	3.13	1.93	2.42	1.17	.80	.28	.86	1.22	1.17	1.18	16.73
1901	2.28	.72	1.46	1.08	2.72	1.43	.80	1.65	2.85	.90	1.25	2.53	19.67

Precipitation at stations in drainage basin of Upper Missouri River—Continued.

HELENA, MONT.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	1.15	0.73	0.83	1.17	1.95	2.26	1.07	0.65	1.33	0.85	0.81	0.85	13.65
1896	.72	.59	1.71	1.23	2.25	.71	.89	.86	2.54	.24	3.29	.35	15.38
1897	.80	1.49	1.23	1.15	1.14	3.66	1.89	.52	.66	.81	2.22	.59	16.16
1898	.20	.52	2.39	.56	4.88	3.52	1.71	.71	.87	1.10	.66	.28	17.40
1899	1.60	.53	1.27	.70	1.98	.84	.63	1.26	.64	1.45	.26	.62	11.78
1900	.03	.64	.90	2.49	3.22	.19	.23	.59	1.39	1.21	.30	.43	11.62
1901	.56	.44	1.05	1.58	4.11	1.83	.40	.17	2.63	.07	.16	1.71	14.71

LIVINGSTON, MONT.

Normal	0.60	0.37	0.76	0.59	3.76	1.92	0.75	0.42	1.28	5.83	0.96	0.36	17.60
1896	37	.10	1.26	.70	2.40	.35	.59	.15	2.37	.83	1.56	T.	10.68
1897	.44	.35	.49	.52	.60	3.30	1.63	T.	.43	1.80	1.66	.55	11.77
1898	T.	.23	1.20	1.04	4.03	4.28	1.23	1.26	.61	1.32	.78	.10	16.08
1899	1.06	1.26	1.20	.50	(3.76)	(1.92)	(.75)	(.42)	(1.28)	(5.83)	.46	1.20	19.64
1900	T.	.14	.44	(.59)	(3.76)	.00	.01	.05	.90	1.20	.03	.40	7.52
1901	(.60)	.01	.05	.77	8.00	1.65	.30	.62	2.10	.25	.23	.94	15.32

Depth of run-off, in inches, from the drainage basin of Middle Creek near Bozeman, Mont.

Year.	Jan.	Feb.	Mar.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1898	.....	.....	.....	10.73	11.42	9.79	8.90	8.40	.....	10.14	8.38
1899	8.91	9.00	8.91	8.73	11.88	10.01	9.35	8.48	8.61	.....	.....
1900	.....	.....	.....	.....	.....	1.87	1.15	.97	.....	.....	.....
Average	8.91	9.00	8.91	9.73	11.65	7.22	6.47	5.95	8.61	10.14	8.38

Depth of run-off, in inches, from the drainage basin of Gallatin River at Logan, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896	0.48	0.44	0.49	0.49	0.77	3.11	0.86	0.49	0.47	0.48	0.47	0.51	9.06
1897	.49	.42	.46	.68	2.69	2.00	.49	.32	.36	.44	.47	.46	9.28
1898	.09	.06	.46	.71	1.69	3.15	.71	.26	.45	.56	.37	(.49)	9.00
1900	.65	.64	.71	.78	2.23	1.55	.23	.24	.33	.43	.48	.45	8.72
Average	.63	.39	.53	.67	1.85	2.45	.57	.33	.40	.48	.45	.48	9.02

Depth of run-off, in inches, from the drainage basin of Madison River at Red Bluff, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.89	0.80	0.89	1.01	1.85	2.36	1.41	0.93	0.82	0.87	0.90	0.93	13.66
1898	.....	.....	.....	.....	.....	3.21	2.01	1.48	1.20	1.20	.....	.....	.....
1899	.....	.....	.....	.....	4.49	2.85	1.51	1.15	1.01	.98	.....	.....	.....
1900	.....	.....	.47	.95	2.36	1.93	1.03	.92	.90	1.03	.89	.91	.....
1901	.61	.55	.61	1.05	2.82	1.80	1.12	.86	.79	.82	.81	.....	.....
Average	.75	.68	.66	1.00	2.88	2.43	1.42	1.07	.94	.98	.87	.92	13.66

Depth of run-off, in inches, from the drainage basin of West Gallatin River at Salesville, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1897	0.33	0.30	0.40	0.75	5.15	3.64	1.76	0.85	0.65	0.70	0.58	0.60	15.71
1898	.81	.97	.75	1.09	3.44	6.02	2.62	1.25	1.04	1.05	.91	1.01	20.96
1899	.93	.84	.90	.94	1.65	7.22	6.12	1.76	1.18	1.14	1.10	1.00	24.78
1900	.81	.60	.67	1.25	4.09	4.23	1.06	.69	.60	.66	.52	.48	15.67
1901	.68	.56	.61	.69	4.89	2.90	1.07	.70	.64	.65	.60	.61	14.60
Average	.71	.63	.67	.94	3.84	4.80	2.53	1.05	1.62	.83	.74	.74	18.34

Depth of run-off, in inches, from the drainage basin of Jefferson River at Sappington, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.20	0.18	0.20	0.41	1.10	0.54	0.30	0.10	0.09	0.12	0.16	0.18	3.58
1898	.20	.18	.17	.44	.77	1.01	.44	.14	.14	.17	.19	.18	4.03
1899	.....	.....	.....	.25	.63	1.36	.80	.25	.16	.21	.25	.11	.....
1900	.....	.....	.....	.38	.83	.50	.13	.07	.09	.17	.19	.20	.....
1901	.....	.....	.....	.29	.89	.47	.15	.07	.08	.10	.13	.....	.....
Average	.20	.18	.19	.35	.84	.78	.36	.13	.11	.15	.18	.17	3.81

Depth of run-off, in inches, from the drainage basin of Missouri River at Townsend, Mont.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.22	0.20	0.24	0.55	1.26	0.87	0.43	0.21	0.20	0.26	0.27	0.29	5.00
1898	1.09	1.05	.36	.46	.81	1.41	.49	.18	.20	.24	.....	.....	.....
1899	.....	.....	.....	.....	.77	2.24	1.12	.39	.26	.31	.31	.35	.....
1900	.54	.73	.69	.46	1.09	.73	.17	.14	.16	.22	.29	.29	5.51
1901	.52	.67	.46	.33	1.20	.70	.23	.12	.13	.21	.22	.73	5.52
Average	.59	.66	.44	.45	1.03	1.19	.49	.21	.19	.25	.27	.42	5.34

Rainfall and run-off in Upper Missouri River Basin.

Stations.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Butte	17.88	10.51	15.24	12.37	16.22	14.55	14.55
Fort Logan	12.14	11.61	15.94	16.62	9.57	8.77	15.72
Fort Yellowstone	21.02	20.77	15.62	17.06	25.84	16.73	19.67
Helena	13.65	15.38	16.16	17.40	11.78	11.62	14.71
Livingston	17.60	10.68	11.77	16.08	19.64	7.52	15.32
Average rainfall	16.46	13.79	14.95	15.91	16.61	11.84	15.99

Rainfall and run-off in Upper Missouri River Basin—Continued.

Stations.	Normal.	1996.	1897.	1898.	1899.	1900.	1901.
RUN-OFF.							
Gallatin at Logan	9.02	9.06	9.28	9.00	.....	8.72	.....
Jefferson at Sappington	3.81	.....	3.58	4.03	.....	.....	.....
Madison at Red Bluff	13.66	.....	13.66	.....	.....	.....	.....
Missouri at Townsend	5.34	5.71	5.00	5.00	.....	5.51	5.52
West Gallatin at Salesville	18.34	17.66	15.71	20.96	.....	15.61	14.60
Average run-off	10.03	5.29	9.45	9.75	.....	9.95	10.06
Percentage of rainfall [a]	60.94	38.36	60.54	61.28	.....	84.05	62.91

[a] This high percentage is probably due to the fact that the rainfall as recorded is that for the lower country, and does not represent the true rainfall on the catchment area.

WEST GALLATIN RIVER.

Estimated monthly discharge of West Gallatin River near Salesville, Mont.

[Drainage area, 860 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	605	455	505	31,051	0.59	0.68
February	495	455	466	26,805	.54	.56
March	475	435	452	27,792	.53	.61
April	700	455	529	31,478	.62	.69
May	7,810	1,230	3,643	223,998	4.24	4.89
June	4,120	1,580	2,233	132,873	2.60	2.90
July	1,440	515	799	49,129	.93	1.07
August	620	495	528	32,465	.61	.70
September	495	475	494	29,395	.57	.64
October	495	475	485	29,821	.56	.65
November	475	435	465	27,669	.54	.60
December	475	455	458	28,161	.53	.61
The year	7,810	435	921	670,637	1.07	14.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 17; rating table on page 170 of same paper.

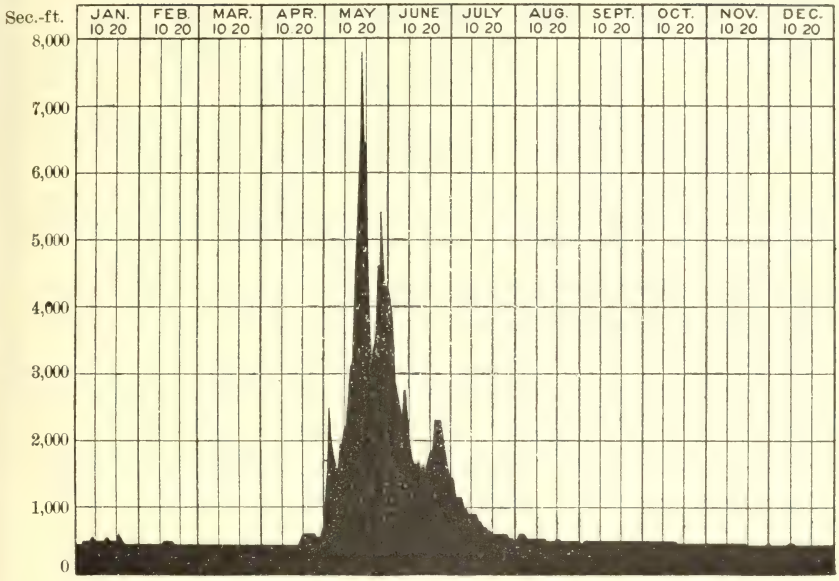


FIG. 36.—Discharge of West Gallatin River near Salesville, Mont., 1901.

MADISON RIVER.

Estimated monthly discharge of Madison River near Red Bluff, Mont.

[Drainage area, 2,085 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 1,106	68,005	0.53	0.61
February			[a] 1,106	61,424	.53	.55
March			[a] 1,106	68,005	.53	.61
April	2,275	1,900	1,958	116,509	.94	1.05
May	8,325	2,825	5,085	312,664	2.44	2.82
June	5,400	2,400	3,357	199,756	1.61	1.80
July	2,400	1,650	2,013	123,774	.97	1.12
August	1,900	1,475	1,560	95,920	.75	.86
September	1,475	1,475	1,475	87,769	.71	.79
October	1,475	1,475	1,475	90,695	.71	.82
November	1,650	1,475	1,516	90,208	.73	.81
December			[a] 1,475	90,695	.71	.82
The year			1,936	1,405,424	.93	12.66

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 19; rating table on page 170 of same paper.

JEFFERSON RIVER.

Estimated monthly discharge of Jefferson River at Sappington, Mont.

[Drainage area, 8,984 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March	.....	.....	1,443	69,491	0.16	0.14
April	5,510	1,260	2,281	135,729	.26	.29
May	9,325	5,730	6,949	427,277	.77	.89
June	7,580	2,375	3,754	223,379	.42	.47
July	2,375	610	1,187	72,986	.13	.15
August	610	550	535	32,896	.06	.07
September	820	430	665	39,570	.07	.08
October	935	820	847	52,080	.09	.10
November	1,155	975	1,057	62,896	.12	.13
December	.....	.....	1,164	43,866	.13	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 19; rating table on page 170 of same paper.

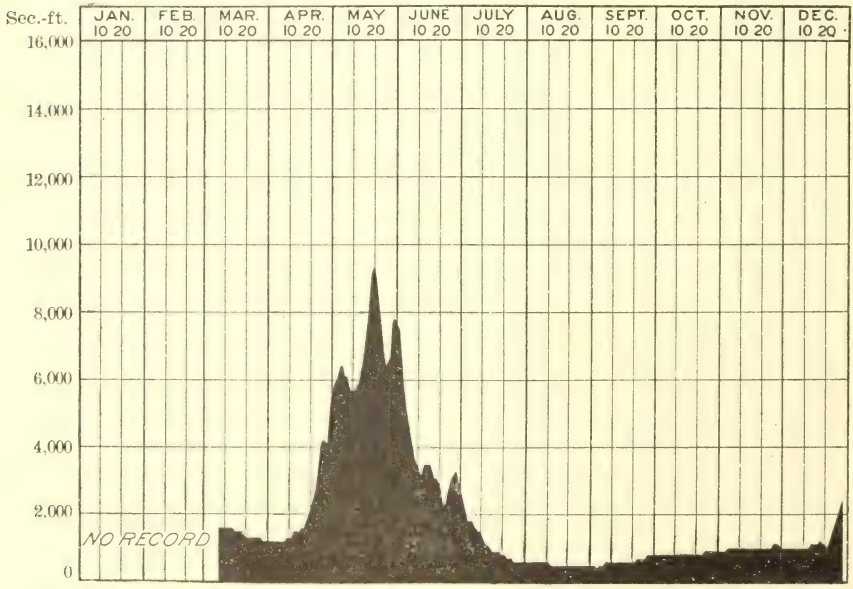


FIG. 37.—Discharge of Jefferson River at Sappington, Mont., 1901.

MISSOURI RIVER.

Estimated monthly discharge of Missouri River near Townsend, Mont.

[Drainage area, 14,500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	8,155	1,020	6,579	404,526	0.45	0.52
February	10,220	7,760	9,296	516,273	.64	.67
March	22,880	3,020	5,884	361,793	.40	.46
April	6,635	2,745	4,340	249,639	.30	.33
May	22,150	7,375	15,029	924,097	1.04	1.20
June	19,450	5,600	9,085	540,595	.63	.70
July	5,600	1,590	2,949	181,327	.20	.23
August	1,800	1,390	1,521	93,522	.10	.12
September	2,020	1,200	1,778	105,798	.12	.13
October	3,020	2,250	2,634	161,958	.18	.21
November	3,020	2,745	2,965	176,429	.20	.22
December	18,825	3,020	9,473	563,682	.65	.73
The year	22,880	1,020	5,961	4,279,639	.41	5.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 21; rating table on page 170 of same paper.

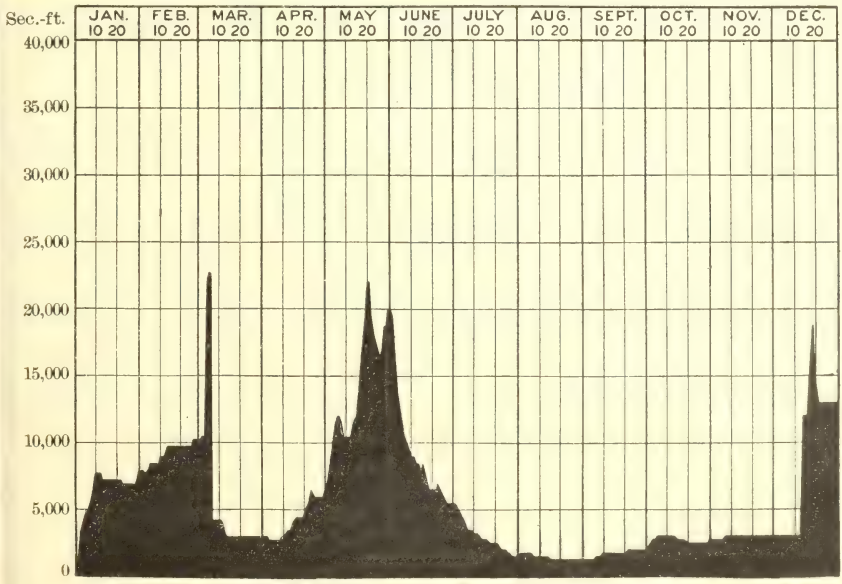


FIG. 38.—Discharge of Missouri River near Townsend, Mont., 1901.

MILK RIVER.

Estimated monthly discharge of Milk River at Havre, Mont.

[Drainage area, 7,300 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March 10–30			600	36,893	0.082	0.095
April	330	115	205	12,198	.028	.031
May	2,540	230	648	39,844	.089	.103
June	1,340	330	553	32,906	.076	.085
July	460	65	184	11,314	.025	.029
August	65	12	28	1,722	.004	.005
September	95	11	56	3,332	.008	.009
October	95	65	82	5,042	.011	.013
November	95	65	80	4,760	.011	.012

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No 66, page 16; rating table on page 170 of same paper.

YELLOWSTONE RIVER.

Estimated monthly discharge of Yellowstone River near Livingston, Mont.

[Drainage area, 3,580 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 1,100	67,636	0.31	0.36
February			[a] 1,000	55,537	.28	.29
March	1,380	1,000	1,264	77,720	.35	.40
April	2,050	1,265	1,489	88,602	.42	.47
May	26,525	2,665	1,218	74,892	.34	.39
June	13,250	8,230	10,228	608,608	2.86	3.19
July	8,075	3,590	5,534	340,273	1.55	1.79
August	4,400	2,440	3,107	191,042	.87	1.00
September	2,560	2,050	2,248	133,765	.63	.70
October	2,050	1,750	1,926	118,425	.54	.62
November			[a] 1,593	94,790	.45	.50
December			[a] 1,200	73,785	.34	.39
The year			2,659	1,925,075	.75	10.10

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 22; rating table on page 170 of same paper.

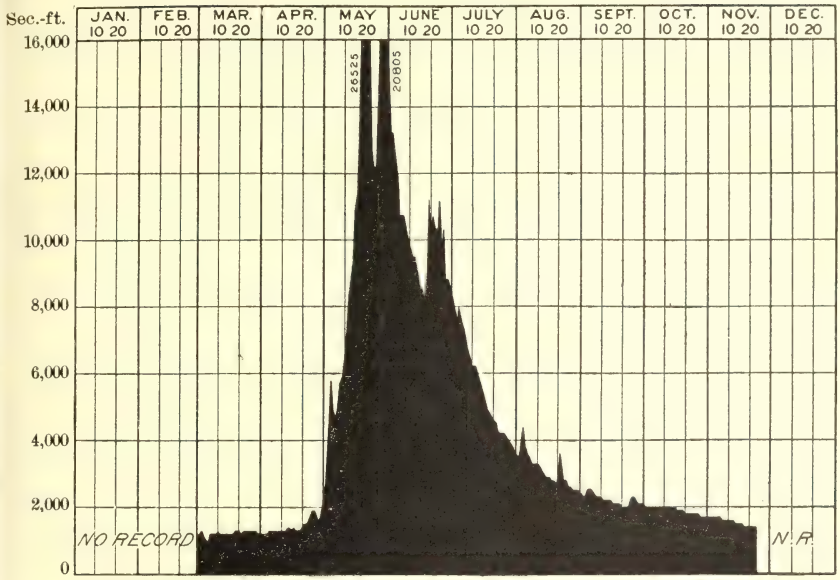


FIG. 39.—Discharge of Yellowstone River near Livingston, Mont., 1901.

Estimated monthly discharge of Bighorn River near Thermopolis, Wyo.

[Drainage area, 8,184 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	17,610	2,980	10,118	622,132	1.24	1.43
June	14,750	5,840	8,739	520,007	1.07	1.19
July	6,830	4,300	5,886	361,916	.72	.83
August	4,410	1,990	2,916	179,298	.36	.42
September	3,530	1,550	2,107	125,376	.26	.29

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 23; rating table on page 170 of same paper.

BIG SIOUX RIVER.

Estimated monthly discharge of Big Sioux River near Sioux Falls, S. Dak.

[Drainage area, 4,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
August 10–31			24	1,047	0.005	.004
September	44	14	26	1,547	.006	.007
October	64	14	45	2,767	.010	.012
November 1–17			50	1,685	.010	.004
1901.						
April 1–20			14	555	.003	.002
May 5–31			97	5,193	.022	.023
June	250	89	168	9,996	.038	.044
July	146	9	44	2,705	.010	.012
August 1–2, 11–31			9	411	.002	.002
September	17	3	14	833	.003	.003
October	21	17	18	1,107	.004	.005
November	31	17	27	1,607	.006	.007

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 24; rating table on page 170 of same paper.

PLATTE RIVER DRAINAGE.

Platte River rises on the eastern slope of the Rocky Mountains in Wyoming, Colorado, and Nebraska. Its headwaters are extensively utilized for irrigation, the most important drainage basin in Colorado being that of South Platte River which traverses a region unequaled in the United States for the extent to which intensive farming has been developed there by irrigation. As in previous years the greater number of river stations maintained in the Platte Basin are located on South Platte River and tributaries in Colorado. New stations were established during the year 1901 at Medicine Bow, Wyo., on Medicine Bow River, a tributary of the North Platte; at Mitchell, Nebr., on North Platte River, and at Kersey, Colo., on South Platte River. The station at Mitchell replaces the one previously maintained at Gering, Nebr., it being situated nearer the Wyoming-Nebraska State line and therefore of greater value in determining the flow at that point. Observations were discontinued at Orchard, Colo., on South Platte River, and the station moved to Kersey, where it is believed better results can be obtained. A detailed report on the

Platte River drainage in Colorado, together with a résumé of all the available records of flow, is contained in Water-Supply Paper No. 74, on the Water Resources of the State of Colorado, by A. L. Fellows.

NORTH PLATTE RIVER.

Estimated monthly discharge of Medicine Bow River at Medicine Bow, Wyo.

[Drainage area, 900 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	1,920	.....	[a] 940	57,798	1.04	1.20
June	1,650	350	977	58,136	1.09	1.22
July	272	45	96	5,903	.11	.12
August	45	6	17	1,045	.02	.02
September	17	8	16	952	.02	.02

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 26; rating table on page 170 of same paper.

Estimated monthly discharge of North Platte River near Guernsey, Wyo.

[Drainage area, 16,243 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	10,435	682	2,066	122,936	0.13	0.15
May	13,217	5,930	8,589	528,117	.53	.61
June	13,880	5,400	9,154	544,701	.56	.62
July	5,532	1,070	1,899	116,765	.12	.14
August	1,070	420	706	43,410	.04	.05
September	420	80	316	18,803	.02	.02

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 27; rating table on page 170 of same paper.

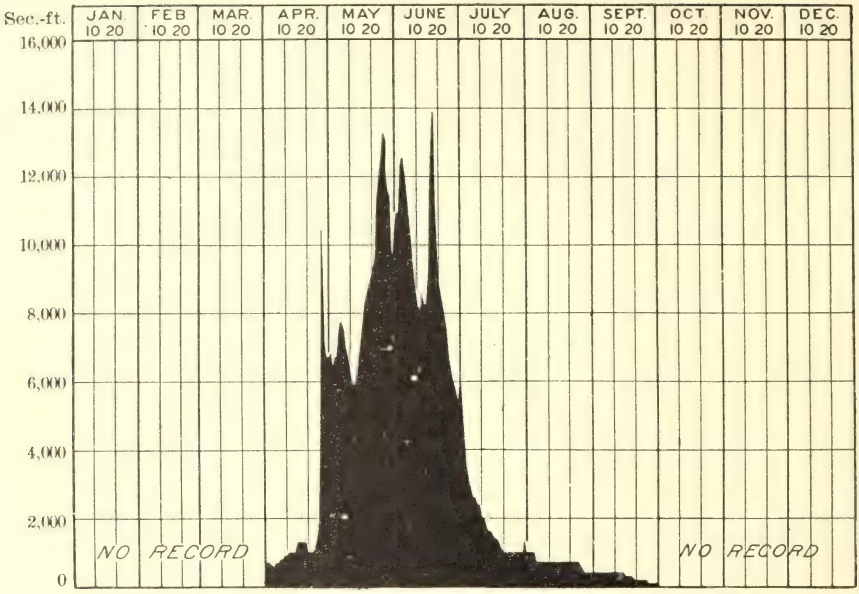


FIG. 40.—Discharge of North Platte River near Guernsey, Wyo., 1901.

Estimated monthly discharge of North Platte River at Mitchell, Nebr.

[Drainage area, 24,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June 9–30			7,514	327,884	0.308	0.252
July 1–20			2,353	96,454	.096	.073
August 12–31			398	16,315	.016	.012
September	422	210	322	19,160	.013	.015
October	520	235	384	23,611	.016	.018

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 28.

SOUTH PLATTE RIVER.

Estimated monthly discharge of South Platte River at Denver, Colo.

[Drainage area, 3,840 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	242	186	212	13,035	0.06	0.07
February	242	186	217	12,052	.06	.06
March	306	213	241	14,818	.07	.08
April	1,121	242	516	30,704	.13	.15
May	1,026	113	553	34,003	.14	.16
June	1,386	113	715	42,545	.19	.21
July	575	25	250	15,310	.07	.08
August	611	242	366	22,443	.10	.12
September	422	51	216	12,853	.06	.07
October	213	25	94	5,657	.02	.02
November	136	12	73	4,284	.02	.02
December	341	113	234	14,388	.06	.07
The year	1,386	12	307	222,092	.08	1.11

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 30; rating table on page 171 of same paper.

Estimated monthly discharge of Bear Creek near Morrison, Colo.

[Drainage area, 170 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	132	11	54	3,213	0.32	0.36
May	168	93	116	7,132	.68	.78
June	187	93	114	6,784	.67	.75
July	96	24	52	3,197	.31	.36
August	190	18	40	2,459	.24	.28
September	51	13	22	1,309	.13	.15
October	29	13	20	1,230	.12	.14
November	21	9	15	893	.09	.10

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 31; rating table on page 171 of same paper.

Estimated monthly discharge of Clear Creek at Forkscreek, Colo.

[Drainage area, 345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May 8–31	.....	.....	[a] 558	34,310	1.62	1.87
June	775	544	652	38,856	1.89	2.11
July	692	235	433	26,624	1.25	1.44
August	367	155	227	14,019	.66	.76
September	179	66	114	6,783	.33	.37
October	93	58	73	4,489	.21	.24
November	58	20	37	2,202	11	.12

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 31; rating table on page 171 of same paper.

Estimated monthly discharge of South Boulder Creek near Marshall, Colo.

[Drainage area, 125 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	119	7	47	2,797	0.38	0.42
May	263	64	128	7,932	1.02	1.18
June	278	193	229	13,627	1.83	2.04
July	220	57	118	7,256	.94	1.08
August	78	34	48	2,951	.38	.44
September	34	13	20	1,190	.16	.18

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 33, rating table on page 171 of same paper.

Estimated monthly discharge of Boulder Creek near Boulder, Colo.

[Drainage area, 179 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	264	6	75	4,463	0.42	0.47
May	705	164	388	23,857	2.17	2.50
June	789	390	513	30,526	2.87	3.20
July	516	191	319	19,615	1.78	2.05
August	225	44	114	7,010	.64	.74
September	70	16	35	2,083	.20	.22
October	32	11	15	922	.08	.09
November	11	6	8	476	.04	.04
December	6	4	5	307	.03	.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 33; rating table on page 171 of same paper.

Estimated monthly discharge of St. Vrain Creek near Lyons, Colo.

[Drainage area, 209 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	253	4	102	6,069	0.49	0.55
May	667	148	337	20,844	1.61	1.86
June	730	304	490	29,157	2.34	2.61
July	478	196	301	18,569	1.44	1.66
August	269	87	157	9,653	.75	.86
September	126	25	59	3,511	.28	.31
October	38	19	30	1,845	.14	.16
November	25	4	14	833	.07	.08

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 35; rating table on page 171 of same paper.

Estimated monthly discharge of Big Thompson Creek near Arkins, Colo.

[Drainage area, 305 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	977	208	600	36,893	1.97	2.27
June	1,143	620	859	51,114	2.82	3.15
July	975	225	530	32,650	1.74	2.01
August	506	140	261	16,048	.86	.99
September	110	44	72	4,284	.24	.27

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 36; rating table on page 171 of same paper.

Estimated monthly discharge of Cache la Poudre River near Fort Collins, Colo.

[Drainage area, 1,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	5,100	619	1,757	108,034	1.66	1.91
June	2,449	1,425	1,956	116,390	1.85	2.06
July 1-23			885	42,129	.83	.74
August	510	242	337	20,721	.32	.37
September	294	98	152	9,045	.14	.16
October 1-15			119	3,540	.11	.06

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 66, page 37.

Estimated monthly discharge of South Platte River at Kersey, Colo.

[Drainage area, 9,470 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	5,856	62	1,393	85,653	0.15	0.17
June	5,004	450	1,820	108,297	.19	.21
July	450	290	314	19,307	.03	.03
August	330	290	296	18,200	.03	.03
September	705	290	395	23,504	.04	.04
October	516	370	456	28,039	.05	.06
November	591	450	526	31,299	.06	.07
December	1,855	540	903	55,524	.10	.12

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 38; rating table on page 171 of same paper.

PRECIPITATION IN THE UPPER BASIN OF SOUTH PLATTE RIVER.

The principal observations of rainfall made within the upper basin of South Platte River are at the stations enumerated in the following table, which also gives their geographic location, elevation above sea

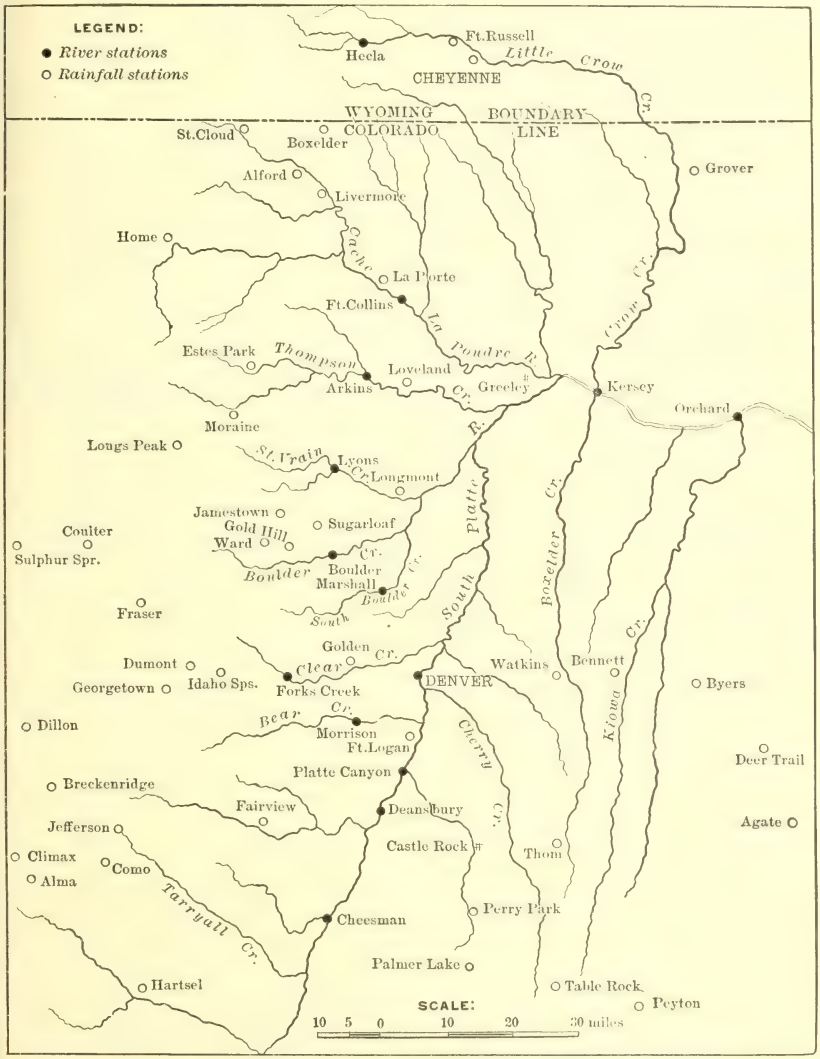


FIG. 41.—Location of rainfall and river stations in the upper basin of South Platte River.

level, and length of record of observations. The relative locations of the points are shown in fig. 41 in connection with the points of river measurement, which are located at Denver, Morrison, Forkscreek, Marshall, Boulder, Lyons, Arkins, Fort Collins, Orchard, and Kersey.

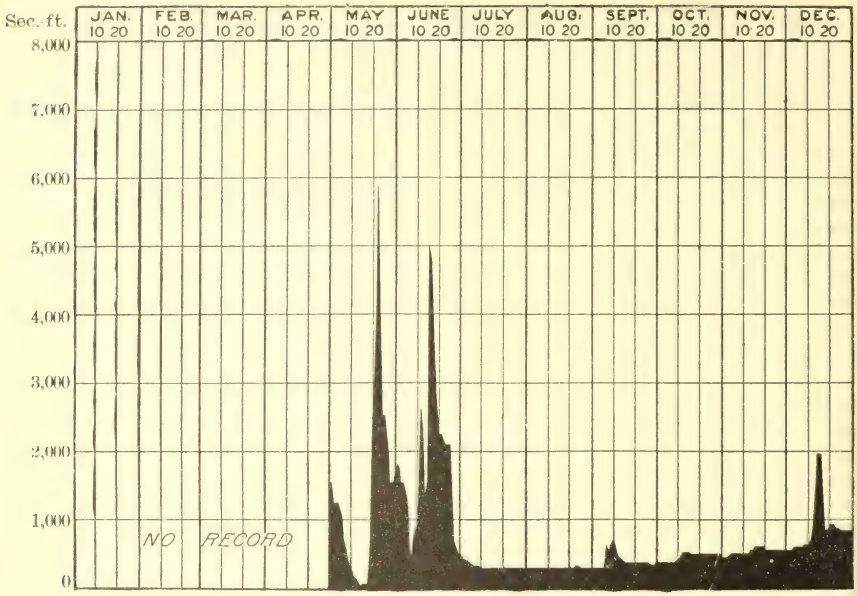


FIG. 42.—Discharge of South Platte River at Kersey, Colo., 1901.

Location of rainfall stations in South Platte River Basin.

Stations.	County.	State.	Latitude.	Longitude.	Elevation.	Length of record.
			° ′	° ′	*Feet.*	*Years.*
Boxelder	Larimer	Colorado				10–12
Breckenridge	Summit	do	39 31	106 0	9,524	11–13
Castlerock	Douglas	do				9–12
Cheyenne	Laramie	Wyoming	41 8	104 48		32
Denver	Arapahoe	Colorado	39 45	105 0	5,281	32
Dumont	Clear Creek	do	40 35	105 2	5,000	10–11
Fort Collins	Larimer	do	40 26	104 42	4,750	19–28
Greeley	Weld	do	40 38	105 6		10–13
Laporte	Larimer	do				11–13
Longs Peak	do	do				6–7
Moraine	do	do				11–13
Sugar Loaf	Boulder	do				10–12

The following table gives the figures of normal or average monthly precipitation from the beginning of the record and including 1901, together with the total precipitation, by months, for the years 1896, 1897, 1898, 1899, 1900, and 1901, and also the annual totals. In obtaining the normal precipitation the average is taken for all of the months during which observations were made.

Precipitation at stations in drainage basin of South Platte River.

BOXELDER, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.70	0.71	1.36	1.93	3.41	1.64	2.20	2.05	0.96	0.74	0.43	0.56	16.69
1896	.53	.06	3.24	1.10	2.53	2.16	1.93	3.05	2.86	.02	.27	.08	17.83
1897	.18	.65	2.75	2.22	3.49	1.59	4.03	4.31	.68	.84	.83	.85	21.42
1898	.70	.22	.58	1.32	5.62	1.66	1.36	1.71	1.36	.47	1.17	.17	16.34
1899	1.27	1.78	1.42	1.06	.52	1.79	2.23	1.46	.13	2.51	.08	.17	14.42
1900	.18	.86	.62	6.70	4.00	.54	2.72	.55	1.55	.00	.00	.21	17.93
1901	.19	.63	1.62	2.96	4.18	1.89	.57	1.66	.49	.46	.13	2.47	17.25

BRECKENRIDGE, COLO.

Normal	2.06	3.51	3.65	3.28	2.37	1.05	2.34	2.16	0.88	1.43	2.41	2.75	27.89
1896	1.88	1.89	4.83	.60	1.47	.30	3.10	2.29	2.25	.82	3.87	.73	24.03
1897	2.90	1.99	3.53	4.00	1.54	1.53	1.70	2.27	1.16	1.02	.60	2.25	24.49
1898	.29	.59	1.16	1.53	.46	1.14	2.19	1.59	.38	1.53	4.09	1.34	16.29
1899	4.75	5.08	7.94	1.31	.31	1.52	2.29	1.60	.29	2.54	.58	1.20	29.41
1900	.35	2.48	1.06	4.82	1.68	1.12	.33	.74	.30	.60	.44	.70	14.62
1901	2.36	3.02	2.40	3.12	2.87	1.58	.89	4.94	.08	.78	.90	2.86	25.80

CASTLEROCK, COLO.

Normal	0.54	0.81	1.03	2.44	2.41	1.82	2.91	2.47	0.73	1.19	0.50	0.75	17.60
1896	.65	.95	1.80	2.30	1.61	.70	3.67	3.57	2.80	1.62	.32	.45	20.44
1897	.47	1.20	2.50	1.37	(2.41)	3.12	3.59	8.10	.24	2.82	(.50)	1.23	27.55
1898	(.54)	(.81)	.40	1.76	6.48	1.82	4.20	1.49	1.35	1.17	1.00	.99	22.01
1899	.63	.67	.77	1.50	.53	1.10	4.48	2.39	T.	1.30	.17	1.16	14.70
1900	.10	.63	.62	7.90	.55	1.80	1.77	.24	.06	.40	.33	.30	14.70
1901	.25	.30	1.04	3.47	1.82	1.35	1.72	3.45	.50	.28	T.	.59	14.77

CHEYENNE, WYO.

Normal	0.39	0.50	0.87	1.64	2.24	1.52	1.96	1.46	0.94	0.68	0.35	0.35	12.90
1896	.68	.31	2.06	2.08	2.85	1.41	6.35	2.52	2.08	.28	.14	.03	20.79
1897	.27	.57	2.32	.60	3.07	1.60	3.77	1.66	.41	1.03	.68	1.27	17.25
1898	.48	.06	.37	.68	3.72	2.33	1.83	.90	.47	.25	1.58	.36	13.05
1899	1.23	1.63	1.89	.97	1.70	.74	3.38	1.15	.07	1.27	.07	.18	14.18
1900	.15	1.25	.72	7.66	.76	1.01	1.20	.70	2.19	.03	.07	.33	16.09
1901	.13	1.10	1.54	2.97	2.47	1.93	1.34	.83	.75	.31	T.	1.62	14.99

DENVER, COLO.

Normal	0.55	0.54	0.93	2.10	2.56	1.33	1.56	1.33	0.83	0.87	0.63	0.66	13.89
1896	.25	.24	1.43	.93	1.27	.89	2.80	.97	1.81	.84	.10	.31	11.84
1897	.58	.82	.90	1.31	3.15	2.16	2.06	1.44	.44	1.64	.24	.63	15.37
1898	.20	.68	.28	1.20	4.88	.94	.67	.96	.28	1.05	.85	.99	12.98
1899	.65	.58	1.10	.75	.15	.47	1.92	1.78	.20	1.01	T.	.72	9.33
1900	.13	.55	.63	8.24	.53	1.87	1.30	.05	.87	.33	.37	.42	15.29
1901	.05	.06	.88	1.96	1.18	2.09	.01	1.30	.22	.46	T.	.89	9.10

Precipitation at stations in drainage basin of South Platte River—Continued.

DUMONT, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.32	0.97	1.39	2.45	3.04	1.60	2.58	2.19	1.14	1.39	0.73	0.78	18.58
1896	.25	.45	2.48	1.22	1.15	.58	2.18	2.81	2.04	.78	.50	.60	15.01
1897	.45	.55	2.00	1.43	3.75	1.71	2.55	2.59	1.42	3.32	.20	.85	20.82
1898	.10	.90	.65	2.45	3.20	2.60	1.67	2.60	.48	.40	1.89	.82	17.76
1899	.60	1.34	2.40	1.45	.62	.76	3.60	2.00	.60	3.55	.42	.85	18.19
1900	.09	1.21	.76	9.23	1.02	2.33	1.37	.75	1.25	.82	.19	.52	19.54
1901	.45	.79	1.22	2.79	2.78	1.15	(2.58)	(2.19)	(1.14)	(1.39)	(.73)	(.78)	17.97

FORT COLLINS, COLO.

Normal	0.61	0.58	0.96	2.21	2.99	1.61	1.88	1.21	0.96	0.94	0.38	0.35	14.68
1896	.43	.03	1.73	1.26	1.68	3.05	3.05	2.20	1.55	.49	.05	.24	15.76
1897	.18	.54	2.15	1.39	2.06	1.69	2.65	1.74	.75	.75	.67	.67	15.24
1898	.14	.08	.50	1.08	3.65	1.37	.50	.98	.50	.82	1.24	.17	11.03
1899	.66	1.04	1.50	1.10	1.01	1.03	4.95	.99	.21	3.23	T.	.47	16.19
1900	.25	1.12	1.07	10.56	1.75	.82	1.14	.16	1.92	.24	.07	.11	19.21
1901	.19	.38	1.88	3.62	7.47	2.35	.71	.57	2.25	.36	.02	1.37	21.17

GREELEY, COLO.

Normal	0.27	0.46	0.67	1.94	2.22	1.42	1.79	0.96	0.56	0.79	0.55	0.29	11.92
1896	.67	.18	.93	1.18	1.42	.46	4.82	2.15	.99	.63	.02	.07	13.52
1897	.06	.61	2.02	.81	3.20	2.47	2.98	1.75	.29	1.11	.40	.38	16.09
1898	.20	.33	.23	(1.94)	5.83	1.69	3.50	.83	.13	.78	.60	.37	16.43
1899	1.14	.69	.71	.70	1.15	.47	2.34	1.04	.30	1.85	T.	.40	10.79
1900	.16	.58	.62	6.32	.96	.31	1.28	T.	1.07	.11	.04	.16	11.61
1901	.22	.45	.95	2.12	2.38	2.45	.26	.47	1.06	.75	.05	1.06	12.22

LAPORTE, COLO.

Normal	0.55	0.72	1.26	2.11	2.94	1.55	1.61	1.28	1.00	0.71	0.41	0.57	14.71
1896	.60	.30	2.70	1.00	2.25	2.59	2.47	1.40	1.27	.50	.01	.40	15.49
1897	.20	.50	2.15	1.62	3.35	1.80	2.51	1.14	2.05	.60	1.10	.70	17.72
1898	.45	.10	.45	.24	5.00	1.27	.67	1.72	.55	.88	1.90	.40	13.63
1899	.89	1.08	1.81	.80	.88	.71	2.62	.95	.18	3.02	.00	.40	13.34
1900	.34	1.47	.79	10.02	1.84	.59	1.75	1.20	1.53	.25	.05	.23	20.06
1901	.05	.27	1.42	4.28	4.32	2.41	.57	.87	.97	.05	.01	1.51	16.73

LONGS PEAK, COLO.

Normal	0.45	0.85	1.74	2.28	1.27	1.47	2.67	1.63	1.06	1.46	0.61	0.54	16.03
1896	.26	.55	3.17	1.00	1.21	.65	3.60	2.95	1.95	1.05	.37	.15	16.91
1897	.78	1.25	1.96	1.45	1.60	1.50	1.85	1.29	.95	1.41	1.07	.55	15.66
1898	.24	.83	.75	1.73	2.07	2.06	2.94	1.53	.81	.60	1.60	.60	15.76
1899	.54	1.15	3.01	1.18	.38	1.09	4.32	1.73	.11	2.50	.02	.64	16.67
1900	.16	.85	.35	6.34	.60	.80	.51	.17	1.93	1.14	.44	.64	13.93
1901	.69	.47	1.19	1.97	1.73	1.47	.85	2.22	1.59	.95	.18	1.00	14.31

Precipitation at stations in drainage basin of South Platte River—Continued.

MORAINE, COLO.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
Normal	0.70	1.42	1.69	2.21	2.66	1.21	2.20	1.81	1.02	1.06	0.70	0.72	17.40
1896	.53	.22	2.87	1.08	1.62	.49	3.88	2.50	2.74	.75	.30	.30	17.28
1897	.61	1.68	1.86	1.29	2.30	1.79	2.52	2.43	.78	1.16	1.25	1.20	18.87
1898	.50	1.05	1.32	1.44	3.05	1.93	2.19	1.67	.40	.99	1.77	.55	16.86
1899	.77	2.32	2.98	1.39	.45	1.57	3.02	1.32	.15	1.96	.00	.65	16.58
1900	.21	1.11	.30	7.74	1.30	.91	.36	.23	2.19	1.42	.47	.48	16.72
1901	.61	.72	1.06	2.36	3.32	1.52	1.43	2.65	.42	.38	.27	1.15	15.89

SUGAR LOAF, COLO.

Normal	1.01	1.32	3.16	2.62	3.85	2.04	2.97	2.75	1.30	1.52	1.17	1.07	24.78
1896	1.10	.40	3.60	1.60	1.15	1.69	3.56	4.45	1.92	1.40	.30	.20	21.37
1897	.40	2.10	6.30	2.81	(3.85)	3.80	3.65	3.91	1.95	3.85	.80	.70	34 12
1898	.90	.90	.80	3.36	3.95	3.51	2.93	2.78	1.30	1.35	2.17	1.18	25.13
1899	1.20	1.22	5.29	1.59	1.11	.74	2.83	3.98	.60	(1.52)	(1.17)	(1.07)	22.32
1900	(1.01)	(1.32)	(3.16)	(2.62)	(3.85)	.95	1.97	1.12	2.97	.60	.20	.97	20.74
1901	.84	.33	2.17	5.60	3.60	2.20	2.80	4.90	.50	.66	.12	1.40	25.12

Depth of run-off, in inches, from the drainage basin of Bear Creek near Morrison, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	1.02	1.15	0.78	1.35	0.44	0.37	0.22	0.14
1898	.....	.74	.93	1.01	.45	.30	.20	.16	.....
1899	.....	.70	.61	.59	.70	.20	.....	.....	.....
1900	.....	3.30	2.49	.78	.33	.....	.20	.11	.....
1901	0.36	.78	.75	.36	.28	.15	.14	.10	.....
Average	.36	1.31	1.19	.70	.62	.27	.23	.15	.14

Depth of run-off, in inches, from the drainage basin of Big Thompson Creek at Arkins, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	1.58	1.68	1.00	0.49	0.13	0.07	0.10	0.15
1898	.....	.62	1.38	.90	.29	.11	.04	.02	.....
1899	0.52	1.14	3.36	2.47	1.07	.33	.24	.....	.....
1900	1.51	5.22	4.94	1.31	.52	.28	.....	.....	.....
1901	.....	2.27	3.15	2.01	.99	.27	.....	.....	.....
Average	1.02	2.17	2.90	1.54	.67	.22	.12	.06	.15

Depth of run-off, in inches, from the drainage basin of Boulder Creek near Boulder, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.09	2.86	2.18	1.37	0.52	0.30	0.23	0.39
1898	.....	1.50	2.79	1.37	.40	.19	.05	.24	.....
1899	0.72	2.27	4.13	3.71	1.71	.55	.25	.14	.....
1900	.....	.76	6.99	2.87	1.06	.60	.37	.....	.....
1901	.47	2.50	3.20	2.05	.74	.22	.09	.04	.03
Average	.60	1.82	3.99	2.44	1.06	.42	.21	19	.22

Depth of n-off, in inches, from the drainage basin of South Platte River at Kersey, Colo.

Year.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1901	0.17	0.21	0.03	0.03	0.04	0.06	0.07	0.12
Average	.17	.21	.03	.03	.04	.06	.07	.12

Depth of run-off, in inches, from the drainage basin of St. Vrain Creek near Lyons, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.82	3.56	2.53	1.51	0.65	0.24	0.19	0.22
1898	.....	1.16	2.30	1.27	.58	.32	.08	.07	.....
1899	1.15	1.43	3.95	3.59	1.65	.46	.22	1.11	.....
1900	.....	3.50	3.32	1.49	.54	.36	.25	.....	.....
1901	.55	1.86	2.61	1.66	.86	.31	.16	.08	.....
Average	.85	2.15	3.15	2.11	1.03	.42	.19	.36	.22

Depth of run-off, in inches, from the drainage basin of South Boulder Creek near Marshall, Colo.

Year.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1897	.....	2.82	3.58	2.17	1.19	0.38	0.36	0.31	0.28
1898	.....	1.79	2.54	1.27	.39	.20	.18	.16	.....
1899	1.02	2.56	3.72	2.24	.84	.31	.....	.....	.....
1900	.....	.....	3.18	.85	.27	.08	.....	.....	.....
1901	.42	1.18	2.04	1.08	.44	.18	.....	.....	.....
Average	.72	2.09	3.01	1.52	.63	.23	.27	.24	.28

Depth of run-off, in inches, from the drainage basin of South Platte River at Denver, Colo.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1897	0.03	0.02	0.05	0.14	0.22	0.30	0.12	0.21	0.08	0.08	0.12	0.06	1.43
1898	.04	.04	.03	.11	.44	.45	.21	.10	.06	.04	.03	.03	1.58
1899	.02	.05	.12	.13	.13	.23	.20	.16	.08	.03	.59	.04	1.78
1900	.06	.05	.06	.48	1.26	.81	.12	.05	.03	.03	.06	.06	2.07
1901	.07	.06	.08	.15	.16	.21	.08	.12	.07	.02	.02	.07	1.11
Average	.04	.04	.07	.20	.44	.40	.15	.13	.06	.04	.16	.05	1.79

Depth of run-off, in inches, from the drainage basin of South Platte River at Orchard, Colo.

Year.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Annual.
1896	0.072	0.026	0.054	.....	.....	.....	.....	.....	.....	.....	.....	0.074	.....
1897	.059	.047	.013	0.048	0.084	0.240	0.032	0.075	0.009	0.029	0.100	.115	0.851
1898	.100	.730	.070	.030	.180	.080	.010	.030	.010	.020	.080	.250	1.590
1899	.280	.280	.220	.120	.044	.110	.150	.071	.004	.040	.072	.150	1.541
1900	.150	.100	.070	.380	.810	.420	.010	.010	.010	.050	.060	.060	2.130
Average	.132	.237	.085	.145	.255	.212	.051	.047	.008	.035	.078	.130	1.528

Rainfall and run-off, South Platte River Basin.

Station.	Normal.	1896.	1897.	1898.	1899.	1900.	1901.
RAINFALL.							
Boxelder	16.69	17.83	21.42	16.34	14.42	17.93	17.25
Breckenridge	27.89	24.03	24.49	16.29	29.41	14.62	25.80
Castlerock	17.60	20.44	27.55	22.01	14.70	14.70	14.77
Cheyenne	12.90	20.79	17.25	13.05	14.18	16.09	14.99
Denver	13.89	11.84	15.37	12.98	9.33	15.29	9.10
Dumont	18.58	15.01	20.82	17.76	18.19	19.54	17.97
Fort Collins	14.68	15.76	15.24	11.03	16.19	19.21	21.17
Greeley	11.92	13.52	16.09	16.43	10.79	11.61	12.22
Laporte	14.71	15.49	17.72	13.63	13.34	20.06	16.73
Longs Peak	16.03	16.91	15.66	15.76	16.67	13.93	14.31
Moraine	17.40	17.28	18.87	16.86	16.58	16.72	15.89
Sugar Loaf	24.78	21.37	34.12	25.13	22.32	20.74	25.12
Average	17.26	17.52	20.38	16.44	16.34	16.70	17.11
RUN-OFF.[a]							
South Platte at Denver	1.790	.....	1.430	1.580	1.780	3.070	1.110
South Platte at Orchard	1.528	.....	.851	1.590	1.541	2.130	.....
Average	1.659	.....	1.141	1.585	1.660	2.600	1.110
Percentage of rainfall	9.61	.....	5.60	9.64	10.16	15.57	6.49

[a] This represents only the excess water over the demands for irrigation, together with the return or seepage waters.

LOUP RIVER.

Estimated monthly discharge of Loup River near Columbus, Nebr.

[Drainage area, 13,542 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	4,681	2,573	3,254	193,626	0.24	0.27
May	2,743	1,847	2,346	144,250	.17	.20
June	5,902	1,723	3,467	206,300	.26	.29
July	3,048	([a])	1,609	98,934	.12	.14
August	1,825	([a])	1,377	84,668	.10	.12
September	4,776	1,763	2,853	169,765	.21	.23
October	2,647	1,898	2,243	137,916	.17	.20
November	3,367	1,743	2,325	138,942	.17	.19

[a] On account of shifting of the bed of the river the low-water flow is somewhat uncertain.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 38.

PLATTE RIVER.

Estimated monthly discharge of Platte River near Columbus, Nebr.

[Drainage area, 56,867 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	28,400	1,300	8,827	525,243	0.16	0.18
May	9,200	2,054	5,300	325,884	.09	.10
June	12,875	5,500	9,363	557,137	.16	.18
July 1–11			1,991	47,389	.04	.02
August	0	0	0	0	.00	.00
September	0	0	0	0	.00	.00
October	0	0	0	0	.00	.00
November	978	375	672	40,641	.01	.01

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 39.

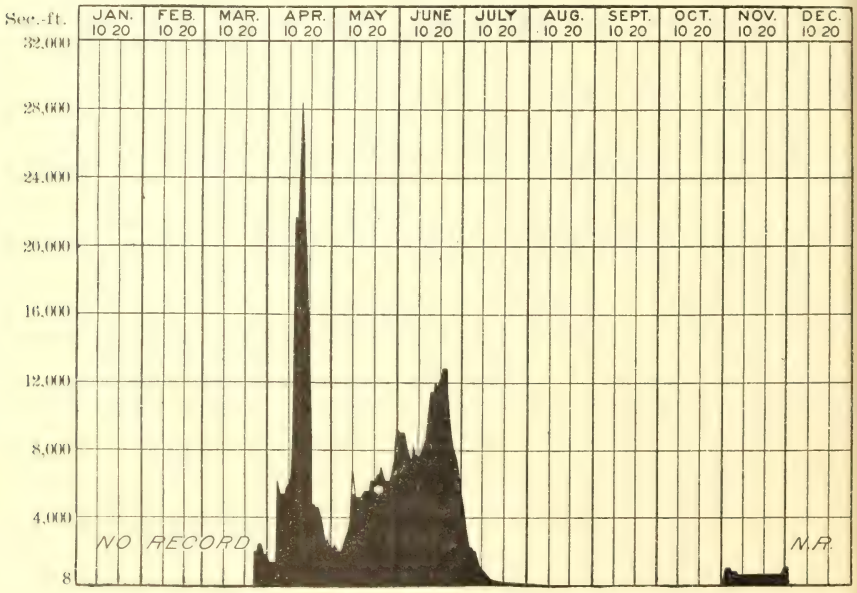


FIG. 43.—Discharge of Platte River near Columbus, Nebr., 1901.

ELKHORN RIVER.

Estimated monthly discharge of Elkhorn River near Norfolk, Nebr.

[Drainage area, 2,474 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	933	431	648	38,559	0.26	0.29
May	881	306	489	30,067	.20	.23
June	3,438	270	1,271	75,630	.51	.57
July	2,003	215	765	47,038	.31	.35
August	231	149	172	10,576	.07	.08
September	362	142	269	16,006	.11	.12
October	342	308	323	19,860	.13	.15
November	357	319	332	19,755	.13	.15

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 40; rating table on page 171 of same paper.

Estimated monthly discharge of Elkhorn River near Arlington, Nebr.

[Drainage area, 5,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,335	833	1,065	63,372	0.18	0.20
May	2,133	613	1,136	69,850	.19	.22
June	4,745	541	1,869	111,213	.31	.35
July	3,989	544	1,373	84,422	.23	.27
August	533	317	421	25,886	.07	.08
September	705	300	514	30,585	.09	.10
October	679	544	599	36,831	.10	.12
November	726	537	627	37,309	.10	.11

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 41.

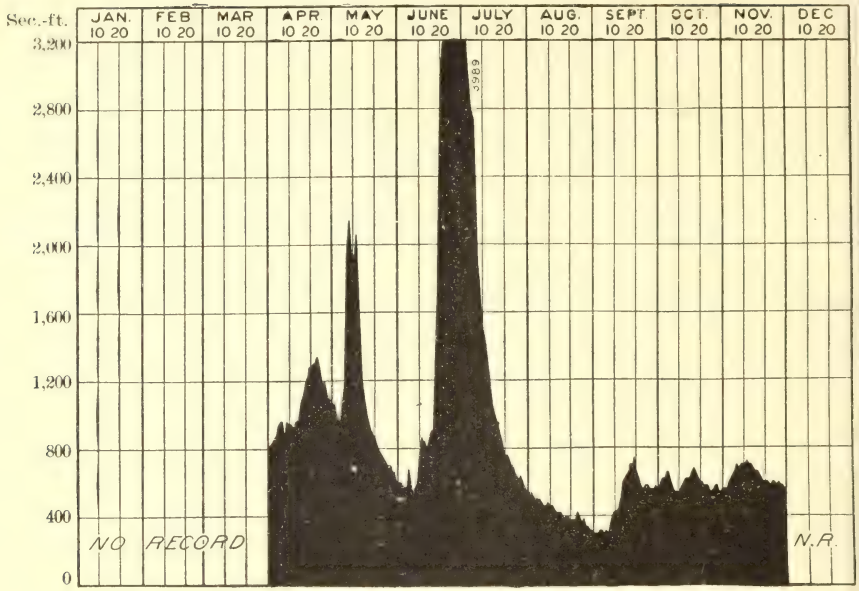


FIG. 44.—Discharge of Elkhorn River near Arlington, Nebr., 1901.

KANSAS RIVER DRAINAGE.

As in previous years systematic measurements were carried on during 1901 at seven points in the basin of Kansas River, the main river being gaged at Lecompton, Kans., and its principal tributaries being gaged at or near their mouths. Kansas River is the largest river which rises in the region of the Great Plains and presents together with its numerous tributaries a typical example of Great Plains drainage.

REPUBLICAN RIVER.

Estimated monthly discharge of Republican River near Superior, Nebr.

[Drainage area, 22,347 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,507	637	961	57,183	0.043	0.048
May	622	146	364	22,381	.016	.018
June	480	117	219	13,031	.010	.011
July	154	5	44	2,618	.002	.002
August	856	5	70	4,304	.003	.003
September	4,991	10	1,246	74,142	.056	.062
October	1,490	285	443	27,239	.020	.020
November	1,030	312	419	24,932	.019	.021

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 41; rating table on page 171 of same paper.

Estimated monthly discharge of Republican River at Junction, Kans.

[Drainage area, 25,837 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	570	405	510	31,359	0.020	0.023
February	1,015	450	669	37,154	.026	.027
March	1,750	850	1,030	63,332	.040	.046
April	5,010	930	1,530	91,041	.059	.066
May	1,015	405	747	45,931	.029	.033
June	510	315	406	24,159	.016	.018
July	450	75	177	10,883	.007	.008
August	110	20	53	3,259	.002	.002
September	3,160	20	906	53,911	.036	.040
October	770	405	564	34,679	.022	.025
November	510	405	472	28,086	.018	.020
December	660	450	594	36,524	.023	.027
The year	5,010	20	638	460,318	.025	.335

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 43; rating table on page 171 of same paper.

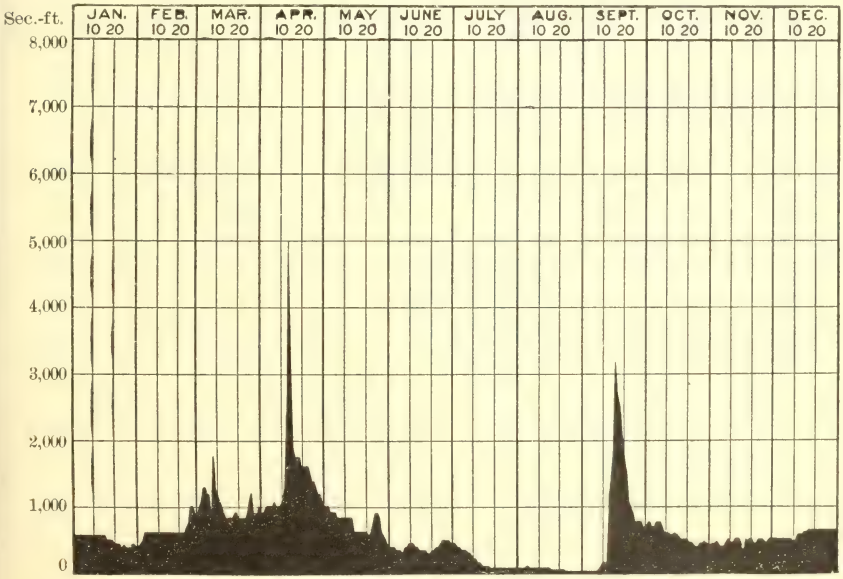


FIG. 45.—Discharge of Republican River at Junction, Kans., 1901.

SOLOMON RIVER.

Estimated monthly discharge of Solomon River near Niles, Kans.

[Drainage area, 6,815 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	114	46	91	5,595	0.013	0.015
February	193	54	90	4,998	.013	.014
March	341	100	152	9,346	.022	.025
April	2,020	114	452	26,896	.066	.074
May	303	89	142	8,731	.021	.024
June	989	46	157	9,342	.023	.026
July	54	7	27	1,660	.004	.005
August	62	7	18	1,107	.003	.003
September	1,604	70	243	14,460	.036	.040
October	89	38	67	4,120	.010	.012
November	176	38	99	5,891	.015	.017
December	100	54	79	4,858	.012	.014
The year	2,020	7	135	97,004	.020	.269

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 44; rating table on page 172 of same paper.

SALINE RIVER.

Estimated monthly discharge of Saline River near Salina, Kans.

[Drainage area, 3,311 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	71	47	56	3,443	0.017	0.020
February	115	55	74	4,110	.022	.023
March	122	51	76	4,673	.023	.027
April	3,580	85	470	27,967	.142	.158
May	315	60	112	6,887	.034	.039
June	2,680	37	376	22,374	.114	.127
July	51	22	31	1,906	.009	.010
August	153	25	47	2,890	.014	.016
September	85	40	53	3,154	.016	.018
October	60	37	47	2,890	.014	.016
November	65	40	53	3,154	.016	.018
December	65	47	57	3,505	.017	.020
The year	3,580	22	121	86,953	.036	.492

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 45; rating table on page 172 of same paper.

SMOKY HILL RIVER.

Estimated monthly discharge of Smoky Hill River at Ellsworth, Kans.

[Drainage area, 7,980 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
anuary	120	18	50	3,074	0.006	0.007
ebruary	165	20	72	3,999	.009	.009
Iarch	50	20	33	2,029	.004	.005
pril	662	23	124	7,378	.016	.018
Iay	81	23	47	2,890	.006	.007
une	142	23	48	2,856	.006	.007
uly	18	5	9	553	.001	.001
ugust	142	5	46	2,828	.006	.007
eptember	142	12	62	3,689	.008	.009
ctober	73	14	36	2,214	.005	.006
ovember	14	8	11	655	.001	.001
ecember	50	12	22	1,353	.003	.003
The year	652	5	47	33,518	.006	.080

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper o. 66, page 45; rating table on page 172 of same paper.

BLUE RIVER.

Estimated monthly discharge of Blue River near Manhattan, Kans.

[Drainage area, 9,490 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
anuary	815	522	682	41,935	0.07	0.08
ebruary	4,082	635	1,471	81,695	.16	.17
Iarch	3,013	770	1,129	69,420	.12	.14
pril	13,155	1,010	2,146	127,696	.23	.26
Iay	2,325	725	1,152	70,834	.12	.14
une	1,500	460	828	49,269	.09	.10
uly	770	305	473	29,084	.05	.06
ugust	2,800	380	775	47,653	.08	.09
eptember	1,010	305	511	30,407	.05	.06
ctober	590	380	470	28,899	.05	.06
ovember	1,325	460	590	35,107	.06	.07
ecember	680	380	498	30,621	.05	.06
The year	13,155	305	894	642,620	.09	1.29

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper o. 66, page 46; rating table on page 172 of same paper.

KANSAS RIVER.

Estimated monthly discharge of Kansas River at Lecompton, Kans.

[Drainage area, 58,550 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,375	1,210	1,772	108,956	0.03	0.03
February	8,820	1,210	3,142	174,497	.05	.05
March	11,110	4,465	6,353	390,631	.11	.13
April	25,000	4,332	12,844	764,271	.22	.25
May	7,005	2,625	4,767	293,111	.08	.09
June	4,465	2,375	3,231	192,258	.06	.07
July	2,625	275	1,123	69,051	.02	.02
August	4,465	275	2,173	133,613	.04	.05
September	6,710	2,375	4,367	259,855	.07	.08
October	5,000	445	2,270	139,577	.04	.05
November	1,885	275	1,222	72,714	.02	.02
December	1,000	625	805	49,498	.01	.01
The year	25,000	275	3,672	2,648,032	.06	.85

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 46; rating table on page 172 of same paper.

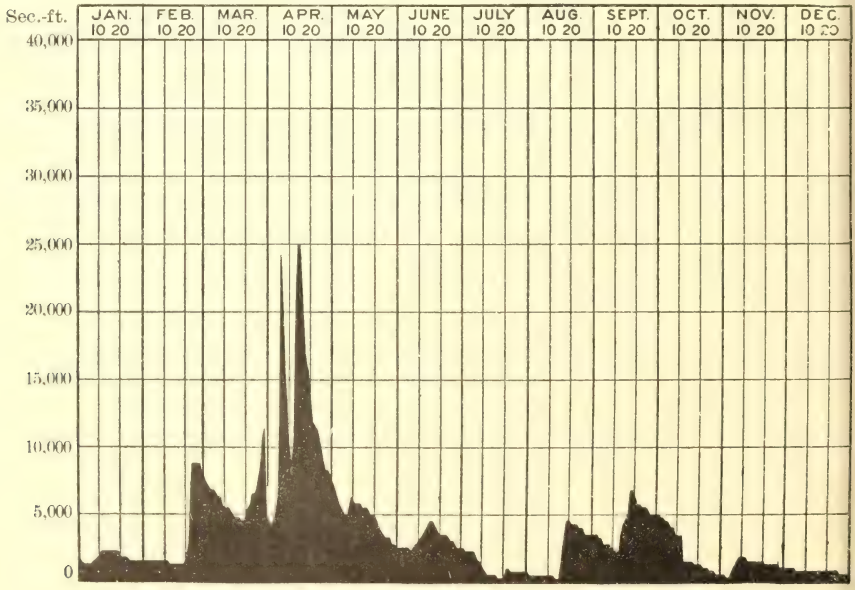


FIG. 46.—Discharge of Kansas River at Lecompton, Kans., 1901.

ARKANSAS RIVER DRAINAGE.

Arkansas River rises in the central portion of Colorado, its headwaters having their source near the summit of the Rockies. The river derives the greater part of its flow from the mountainous regions of Colorado, its volume diminishing greatly as it approaches the level of the plains through constant diversion for irrigation purposes. By far the greater number of gaging stations maintained in the Arkansas River Basin are located in the irrigation districts of Colorado. During 1901 a station was established near Barton, Colo., a few miles west of the Kansas line, the records of which will be of value in determining the amount of water passing from Colorado into Kansas. As in previous years, stations were maintained in Kansas on the Arkansas proper at Hutchinson, on Verdigris River near Liberty, and on Neosho River near Iola. A detailed report on the Arkansas River drainage in Colorado, together with a résumé of all the available records of flow, is contained in Water-Supply Paper No. 74, on the Water Resources of the State of Colorado, by A. L. Fellows.

ARKANSAS RIVER.

Estimated monthly discharge of Arkansas River near Canyon, Colo.

[Drainage area, 3,060 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	663	217	373	22,195	0.12	0.13
May	3,799	442	1,681	103,300	.55	.63
June	2,633	1,690	2,182	129,938	.71	.79
July	1,912	407	795	48,883	.26	.30
August	1,967	407	630	38,737	.21	.24
September	715	270	352	20,945	.12	.13
October	377	270	313	19,246	.10	.12

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 49; rating table on page 172 of same paper.

Estimated monthly discharge of Arkansas River at Pueblo, Colo.

[Drainage area, 4,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	625	430	474	29,145	0.10	0.12
February	430	254	414	22,992	.09	.09
March	380	254	322	19,799	.07	.08
April	932	234	547	32,549	.12	.13
May	11,060	625	1,784	109,694	.39	.41
June	4,326	1,660	2,347	139,656	.51	.56
July	2,662	338	1,004	61,733	.22	.25
August	1,560	430	776	47,714	.17	.20
September	1,367	214	429	25,527	.09	.10
October	430	254	321	19,737	.07	.08
November	430	254	328	19,517	.07	.08
December	698	296	447	27,485	.10	.11
The year	11,060	214	803	555,548	.17	2.21

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 50; rating table on page 172 of same paper.

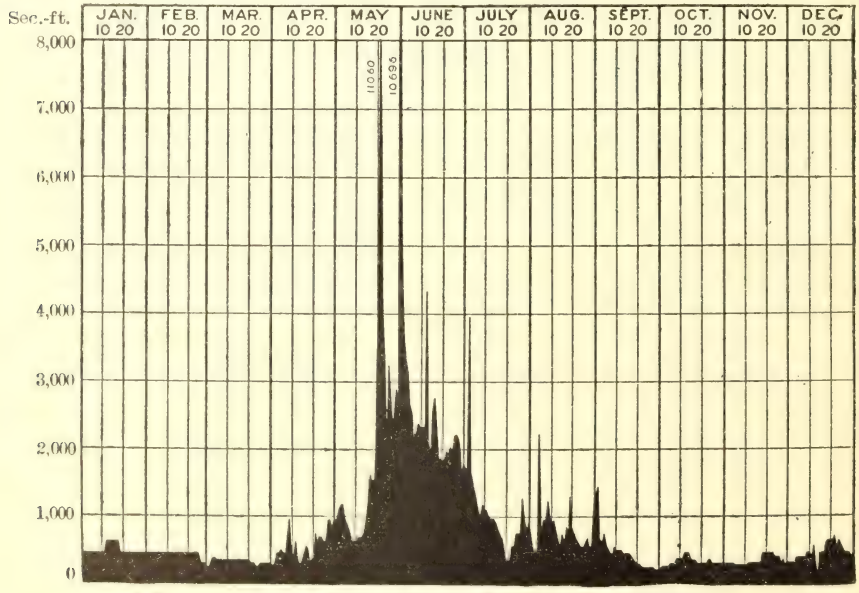


FIG. 47.—Discharge of Arkansas River at Pueblo, Colo., 1901.

Estimated monthly discharge of Arkansas River at Prowers, Colo.

[Drainage area, 19,180 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	120	36	60	3,689	0.003	0.003
February	103	25	64	3,554	.003	.003
March	50	25	40	2,460	.002	.002
April	61	15	41	2,440	.002	.002
May	2,546	48	564	34,679	.029	.033
June	6,086	120	2,129	126,684	.111	.124
July	658	36	176	10,822	.009	.010
August	2,782	48	518	31,851	.027	.031
September	658	10	120	7,140	.006	.007
October	88	10	46	2,828	.002	.002
November	88	36	59	3,510	.003	.003
December	120	25	55	3,382	.003	.003
The year	6,086	10	323	233,039	.017	.223

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 53; rating table on page 172 of same paper.

Estimated monthly discharge of Arkansas River at Hutchinson, Kans.

[Drainage area, 34,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	140	80	94	5,780	0.003	0.003
February	530	80	167	9,275	.005	.005
March	295	140	171	10,514	.005	.006
April	960	140	375	22,314	.011	.012
May	190	100	146	8,977	.004	.005
June	2,820	100	747	44,450	.022	.025
July	205	30	83	5,103	.002	.002
August	60	20	27	1,660	.001	.001
September	205	20	64	3,808	.002	.002
October	140	45	76	4,673	.002	.002
November	52	37	39	2,321	.001	.001
December	70	37	45	2,767	.001	.001
The year	2,820	20	169	121,642	.005	.065

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 56; rating table on page 172 of same paper.

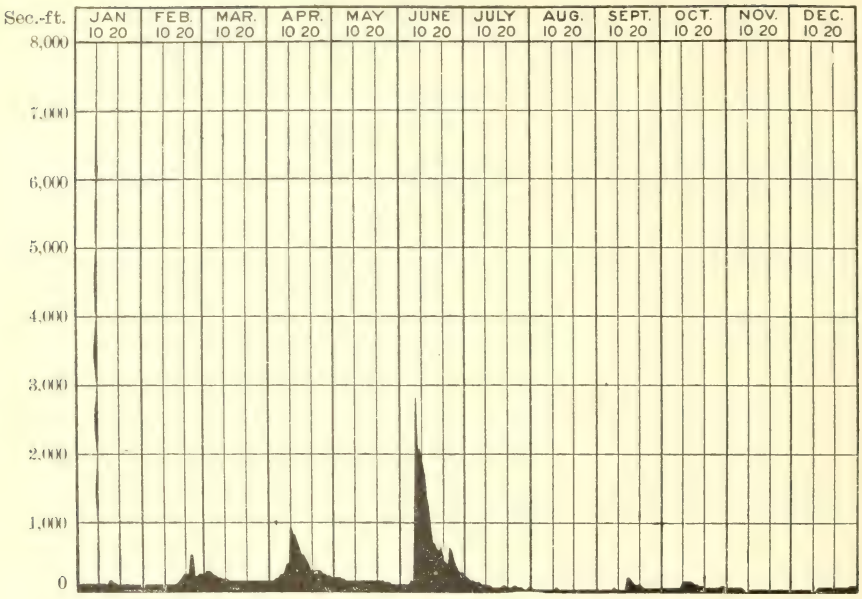


FIG. 48.—Discharge of Arkansas River at Hutchinson, Kans., 1901.

VERDIGRIS RIVER.

Estimated monthly discharge of Verdigris River near Liberty, Kans.

[Drainage area, 3,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	860	280	465	28,592	0.151	0.174
February	2,200	368	920	51,094	.300	.312
March	7,458	368	1,006	61,857	.328	.379
April	16,260	760	3,272	194,697	1.067	1.195
May	2,550	90	554	34,064	.181	.209
June	810	40	122	7,259	.040	.045
July	90	3	13	799	.004	.005
August	205	2	30	1,845	.010	.012
September	2,200	2	153	9,104	.050	.056
October	90	40	55	3,382	.018	.021
November	40	27	37	2,202	.012	.013
December	55	40	51	3,136	.017	.020
The year	16,260	2	556	398,031	.182	2.441

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

NEOSHO RIVER.

Estimated monthly discharge of Neosho River near Iola, Kans.

[Drainage area, 3,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	985	353	444	27,300	0.121	0.140
February	3,570	353	1,224	67,978	.334	.348
March	1,900	552	999	61,426	.272	.314
April	19,250	1,382	6,969	414,684	1.899	2.119
May	1,500	678	1,065	65,484	.290	.334
June	4,250	450	955	56,826	.260	.290
July	353	190	254	15,618	.069	.080
August	190	154	178	10,945	.048	.055
September	142	58	102	6,069	.028	.031
October	58	10	33	2,029	.009	.010
November	70	10	32	1,904	.009	.010
December	94	10	35	2,152	.010	.012
The year	19,250	10	102	732,415	.279	3.743

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 57; rating table on page 172 of same paper.

WESTERN GULF DRAINAGE.

During 1901 measurements were continued on the Brazos River at Waco, Tex., and on the Colorado River at Austin, Tex. Results of measurements are here published for the Waco station for the entire period of observation, 1898 to 1901. A hydrographic reconnaissance was made during the month of December, 1901, by Prof. Thomas U. Taylor, of a number of Texas streams, the results of which reconnaissance are published in Water-Supply Paper No. 66, pages 58 to 63. Descriptions of the principal irrigation systems of Texas deriving their water supply from rivers or wells in that State are contained in Water-Supply Paper No. 71, entitled Irrigation Systems of Texas, by Prof. Thomas U. Taylor.

Systematic measurements were kept during 1901 at fifteen gaging stations scattered along the Rio Grande and its tributaries, the first station being at Del Norte, at the head of the San Luis Valley, Colorado, and the last station at Eagle Pass, Tex. The stations along the Lower Rio Grande are maintained by the International (Water) Boundary Commission.

The accompanying diagrams, figs. 50, 51, and 52, furnish an interesting graphic comparison of the discharge of the Rio Grande near El Paso, below Presidio, and near Eagle Pass for 1900 and 1901.

BRAZOS RIVER.

Estimated monthly discharge of Brazos River at Waco, Tex.

[Drainage area, 30,750 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1898.						
September 14–30			797	26,874	0.026	0.016
October	1,126	95	347	21,336	.011	.013
November	145	61	85	5,058	.003	.003
December	721	61	144	8,854	.005	.006
1899.						
January	179	76	116	7,133	.004	.005
February	95	61	82	4,554	.003	.003
March	68	26	41	2,521	.001	.001
April	2,968	26	161	9,580	.005	.006
May	5,085	40	1,457	89,587	.047	.054
June	70,682	668	11,203	666,624	.364	.526
July	50,110	1,800	10,945	672,981	.356	.407
August	2,185	118	533	32,773	.017	.019
September	106	50	74	4,403	.002	.002
October	16,750	32	1,127	67,075	.037	.043
November	77,076	365	7,582	451,160	.246	.277
December	11,600	748	2,974	182,864	.097	.112
The year	77,076	26	3,025	2,191,255	.098	1.455
1900.						
January	9,620	860	1,914	117,687	.062	.071
February	830	365	615	34,155	.020	.021
March	3,435	315	791	48,637	.026	.030
April	83,094	668	15,585	927,371	.507	.566
May	46,218	3,365	9,092	559,045	.292	.332
June	35,095	1,322	6,090	362,380	.198	.221
July	10,240	1,220	3,148	193,563	.102	.114
August	5,277	540	2,257	138,777	.073	.084
September	98,832	365	22,213	1,321,767	.722	.802

Estimated monthly discharge of Brazos River at Waco, Tex.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October	35,376	1,082	4,953	304,548	.161	.186
November	12,150	775	1,826	108,655	.059	.066
December	775	415	575	35,355	.019	.022
The year	98,832	315	5,755	4,151,940	.187	2.515
1901.						
January	415	267	344	21,213	.011	.013
February	616	221	392	21,771	.013	.014
March	415	145	232	14,265	.008	.009
April	1,172	179	560	33,322	.020	.018
May	38,017	76	3,670	225,660	.119	.137
June	18,974	221	2,944	175,180	.096	.107
July	267	61	107	6,479	.003	.003
August	1,126	68	431	39,332	.022	.025
September	3,100	61	662	26,501	.014	.016
October	565	95	246	15,126	.008	.009
November	748	76	303	18,030	.010	.011
December	267	76	136	8,362	.004	.005
The year	38,017	61	836	605,241	.026	.367

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 59; rating table on page 173 of same paper.

COLORADO RIVER.

Estimated monthly discharge of Colorado River at Austin, Tex.

[Drainage area, 37,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,704	2,306	2,569	157,962	0.07	0.08
February	2,306	1,908	1,920	106,631	.05	.05
March	1,908	1,190	1,455	89,464	.04	.05
April	3,102	980	1,490	88,661	.04	.04
May	8,674	980	3,148	193,624	.09	.10
June	7,480	290	1,996	118,770	.05	.06
July	40,912	210	4,037	248,225	.11	.13
August	1,908	175	558	34,310	.02	.02
September	21,808	210	4,161	247,597	.11	.13
October	825	290	415	25,517	.01	.01
November	10,664	290	1,690	10,056	.05	.06
December	580	380	484	29,760	.01	.01
The year	40,912	175	1,994	1,350,577	.05	.74

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 64; rating table on page 173 of same paper.

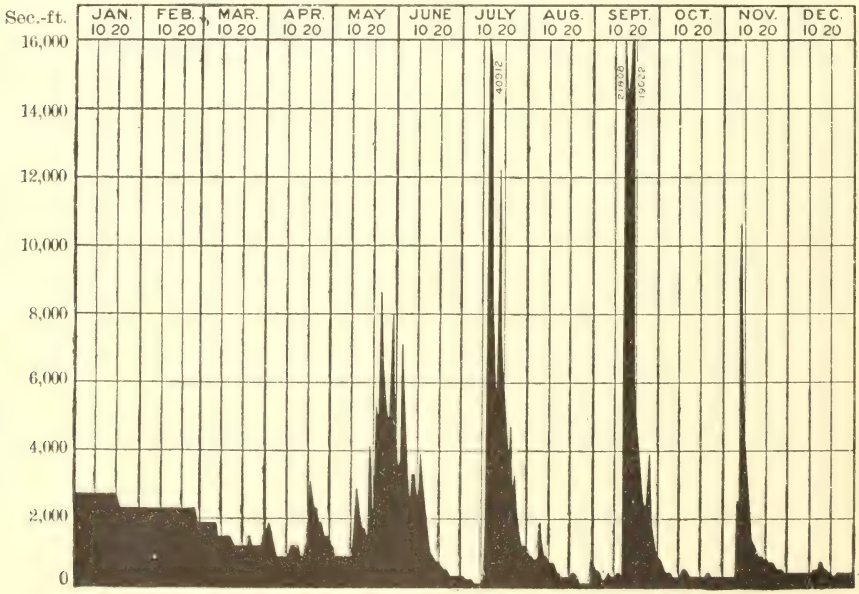


FIG. 49.—Discharge of Colorado River at Austin, Tex., 1901.

RIO GRANDE.

Estimated monthly discharge of Rio Grande near Del Norte, Colo.

[Drainage area, 1,400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a]800	49,190	[a]0.57	[a]0.66
February			[a]900	49,983	[a].64	[a].67
March			[a]500	30,744	[a].36	[a].40
April	1,734	289	710	42,248	.51	.57
May	4,479	1,463	2,570	158,023	1.84	2.12
June	2,754	1,149	1,782	116,036	1.27	1.42
July	1,063	384	594	36,524	.42	.48
August	660	320	464	28,530	.33	.38
September	895	258	446	26,539	.32	.36
October	320	228	262	16,110	.19	.22
November			283	16,840	.20	.22
December			366	22,504	.26	.30
The year			806	593,271	.58	7.80

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 65; rating table on page 173 of same paper.

Estimate monthly discharge of Rio Grande at Cenicero, Colo.

[Drainage area, 7,695 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	594	594	594	36,524	0.0770	0.0890
February	594	414	581	32,267	.0760	.0790
March	774	107	365	22,443	.0470	.0540
April	1,044	107	278	16,542	.0360	.0400
May	2,664	1,224	1,680	103,299	.2180	.2500
June	1,854	236	1,032	61,408	.1340	.1500
July	236	22	82	5,041	.0110	.0130
August	142	31	60	3,689	.0078	.0090
September	58	43	50	2,975	.0063	.0070
October	79	43	54	3,320	.0072	.0083
November	142	43	72	4,284	.0094	.0105
December	414	142	337	20,721	.0440	.0510
The year	2,664	22	432	312,513	.0561	.7608

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 65; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande at Embudo, N. Mex.

[Drainage area, 10,090 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches
1901.						
January	400	280	341	20,967	0.034	0.03
February	680	350	466	25,880	.046	.04
March	680	350	518	31,851	.051	.05
April	2,020	350	628	37,369	.062	.06
May	6,950	1,700	3,461	212,809	.343	.39
June	4,200	530	1,714	101,990	.170	.19
July	9,700	220	398	24,472	.039	.04
August	1,470	300	451	27,730	.045	.05
September	590	300	359	21,362	.036	.04
October	540	300	331	20,352	.033	.03
November	460	340	359	21,362	.036	.04
December	500	360	423	26,009	.042	.04
The year	9,700	220	787	572,153	.078	1.06

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 66; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande at Rio Grande, N. Mex.

[Drainage area, 14,050 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	610	255	397	24,410	0.028	0.032
February	1,360	420	658	36,543	.047	.049
March	1,275	390	742	45,624	.053	.061
April	4,940	420	1,402	83,425	.100	.112
May	8,400	4,000	5,194	319,367	.370	.430
June	4,740	815	2,199	130,850	.157	.175
July	2,930	280	729	44,824	.052	.060
August	3,450	200	827	50,850	.059	.068
September	2,295	280	580	34,512	.041	.046
October	1,870	320	491	30,190	.035	.040
November	580	380	462	27,491	.033	.037
December	640	260	463	28,468	.033	.038
The year	8,400	200	1,179	856,554	.084	1.148

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 67; rating table on page 173 of same paper.

Estimated monthly discharge of Rio Grande near San Marcial, N. Mex.

[Drainage area, 28,067 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	450	30	341	20,967	0.0121	0.0140
February	1,000	290	458	25,468	.0163	.0170
March	480	30	246	15,114	.0088	.0101
April	3,560	0	398	23,683	.0142	.0158
May	5,570	2,880	4,165	256,126	.1484	.1711
June	4,740	60	1,616	96,178	.0574	.0640
July	6,600	0	964	59,286	.0341	.0394
August	5,865	120	1,066	65,534	.0379	.0437
September	6,210	0	632	37,607	.0225	.0251
October	2,320	0	277	17,018	.0099	.0114
November	1,460	160	337	20,053	.0120	.0134
December	460	230	313	19,240	.0111	.0128
The year	6,600	0	901	656,274	.0320	.4388

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 68.

Estimated monthly discharge of Rio Grande near El Paso, Tex.

[Drainage area, 30,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	30	0	5	278	0.0002	0.0002
February	270	0	81	4,503	.0027	.0028
March	410	0	60	3,669	.0016	.0018
April	0	0	0	0	.0000	.0000
May	3,980	110	2,571	158,102	.0857	.0988
June	3,620	20	1,295	77,038	.0432	.0482
July	2,480	0	205	12,576	.0068	.0078
August	3,070	90	986	60,655	.0329	.0379
September	2,650	0	353	21,005	.0118	.0132
October	450	0	87	5,336	.0029	.0033
November	810	40	215	12,813	.0072	.0080
December	130	130	130	7,993	.0043	.0050
The year	3,980	0	499	363,968	.0166	.2270

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 70.

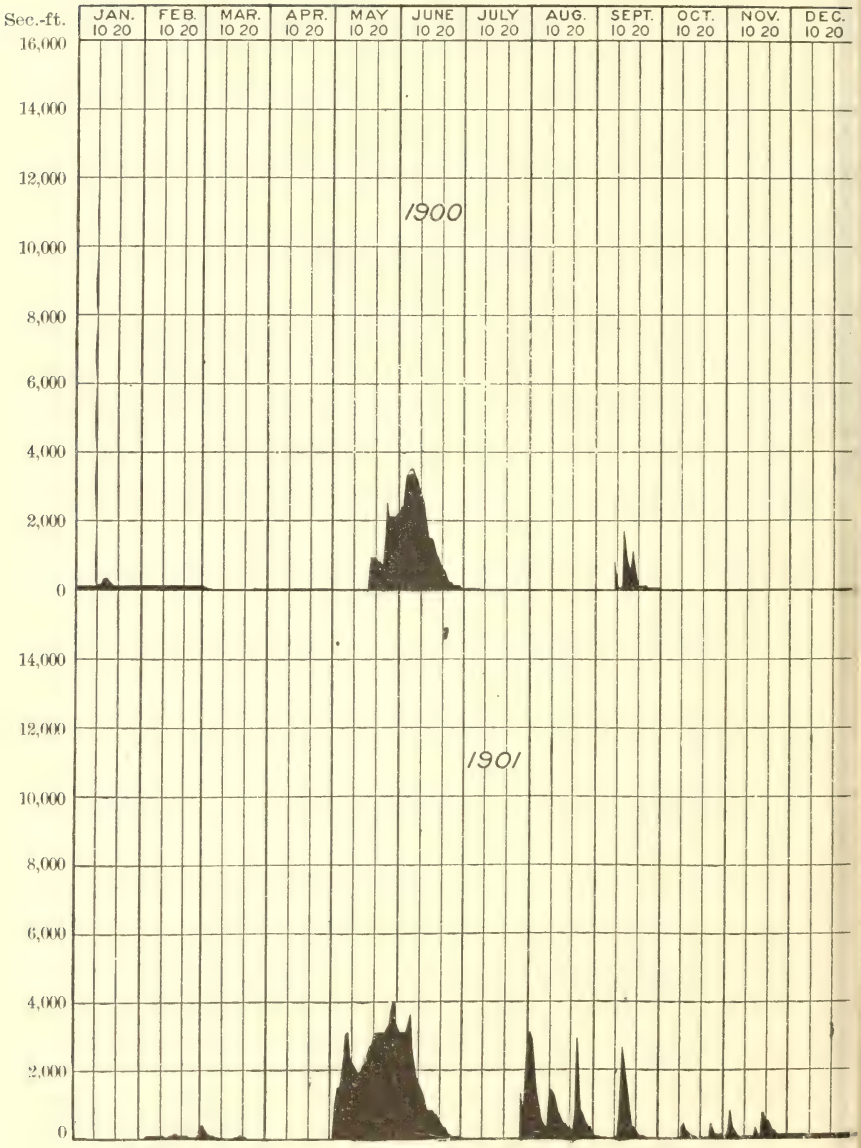


FIG. 50.—Discharge of Rio Grande near El Paso, Tex., 1900-1901.

Estimated monthly discharge of Rio Grande near Fort Hancock, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	2,680	0	1,742	107,127
June	2,710	0	1,015	60,417
July	1,250	0	67	4,126
August	1,770	0	622	38,221
September	1,800	0	241	14,321
October	630	0	94	5,752
November	1,000	30	210	12,476
December	450	40	123	7,736
The year	2,710	0	343	250,176

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 71.

Estimated monthly discharge of Rio Grande above Presidio, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	0	0	0	0
February	0	0	0	0
March	0	0	0	0
April	0	0	0	0
May	1,370	0	770	47,326
June	1,620	0	731	43,478
July	830	0	137	8,450
August	1,270	10	462	28,423
September	1,780	30	453	26,936
October	970	0	185	11,365
November	1,020	30	157	9,322
December	130	60	81	4,979
The year	1,780	0	248	180,279

NOTE.—Gage heights and discharge measurements for 1901 are given in Water Supply Paper No. 66, page 72.

Estimated monthly discharge of Rio Grande below Presidio, Tex. (including the flow of Conchos River).

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	200	160	181	11,107
February	780	160	314	17,434
March	440	80	198	12,198
April	80	20	41	2,420
May	1,300	20	720	44,291
June	1,530	50	763	45,422
July	3,470	20	999	61,408
August	3,120	820	1,793	110,241
September	5,410	640	2,206	131,266
October	5,690	330	1,223	75,213
November	1,500	330	593	35,266
December	450	260	300	18,466
The year	5,690	20	778	564,732

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 74.

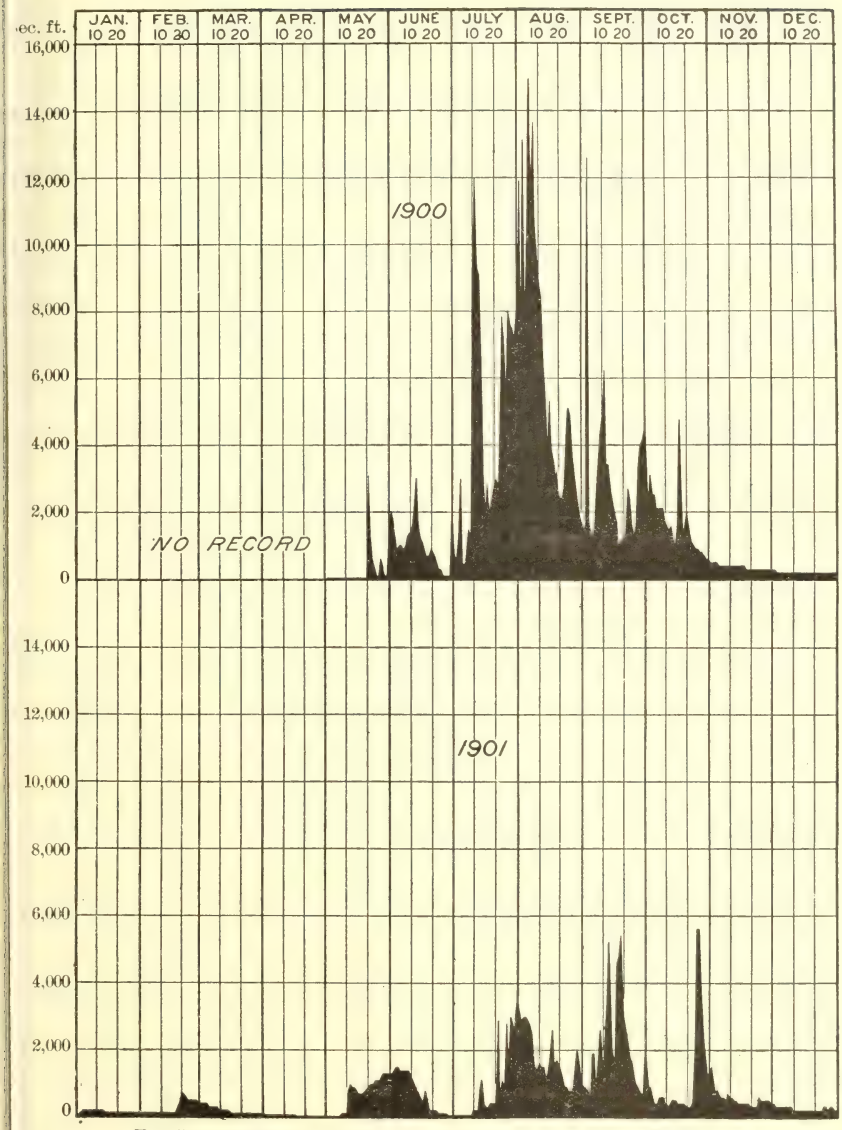


FIG. 51.—Discharge of Rio Grande below Presidio, Tex., 1900-1901.

Estimated monthly discharge of Rio Grande near Langtry, Tex.

Month.	Discharge in second-feet.			Total in acre feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	620	570	600	36,89
February	920	520	599	33,26
March	890	450	627	38,55
April	920	370	425	25,30
May	3,500	450	1,163	71,52
June	2,350	600	1,465	87,17
July	3,510	500	1,314	80,76
August	3,920	820	2,306	141,81
September	14,700	1,210	3,418	203,38
October	5,120	1,100	1,900	116,84
November	2,610	930	1,367	81,32
December	1,120	800	875	53,77
The year	14,700	370	1,338	970,63

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Pape No. 66, page 75.

Estimated monthly discharge of Pecos River near Moorhead, Tex.

Month.	Discharge in second-feet.			Total in acre feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	570	440	508	31,24
February	610	500	563	31,26
March	530	360	443	27,21
April	380	280	306	18,20
May	670	280	348	21,42
June	440	190	321	19,12
July	1,270	160	341	20,94
August	1,220	200	688	42,30
September	9,200	350	1,295	77,07
October	850	420	561	34,51
November	2,690	490	1,435	85,36
December	1,200	500	790	48,57
The year	9,200	160	633	457,24

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Pape No. 66, page 78.

Estimated monthly discharge of Devils River at Devilsriver, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	840	810	831	51,074
February	840	750	801	44,489
March	830	720	748	46,017
April	750	670	685	40,760
May	670	660	665	40,919
June	670	580	604	35,921
July	750	570	583	35,841
August	670	500	556	34,215
September	700	510	529	31,478
October	520	520	520	31,974
November	520	510	515	30,664
December	510	480	489	30,069
The year	840	480	627	453,421

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 79.

Estimated monthly discharge of Rio Grande near Devilsriver, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	2,330	2,160	2,277	140,033
February	2,870	2,120	2,260	125,497
March	2,570	1,920	2,180	133,964
April	2,070	1,620	1,719	102,288
May	3,610	1,750	2,189	134,588
June	3,770	1,950	2,669	158,816
July	5,250	1,830	2,452	150,783
August	6,000	2,650	3,907	240,218
September	34,280	2,490	5,863	348,873
October	11,500	2,630	3,938	242,122
November	5,180	2,969	3,897	231,888
December	3,350	2,360	2,748	168,992
The year	34,280	1,620	3,008	2,178,062

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 80.

Estimated monthly discharge of Rio Grande near Eagle Pass, Tex.

Month.	Discharge in second-feet.			Total in acre-feet.
	Maximum.	Minimum.	Mean.	
1901.				
January	3,420	2,750	3,054	187,795
February	2,740	2,510	2,616	145,369
March	2,610	2,020	2,277	140,033
April	2,300	1,780	1,934	115,081
May	4,410	2,200	3,108	191,107
June	5,430	1,770	3,571	212,509
July	3,800	1,600	2,376	146,122
August	5,240	2,800	4,249	261,243
September	21,460	2,840	5,593	332,807
October	7,600	2,380	3,444	211,775
November	4,400	2,680	3,644	216,833
December	2,670	2,010	2,245	138,089
The year	21,460	1,600	3,176	2,298,763

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 81.

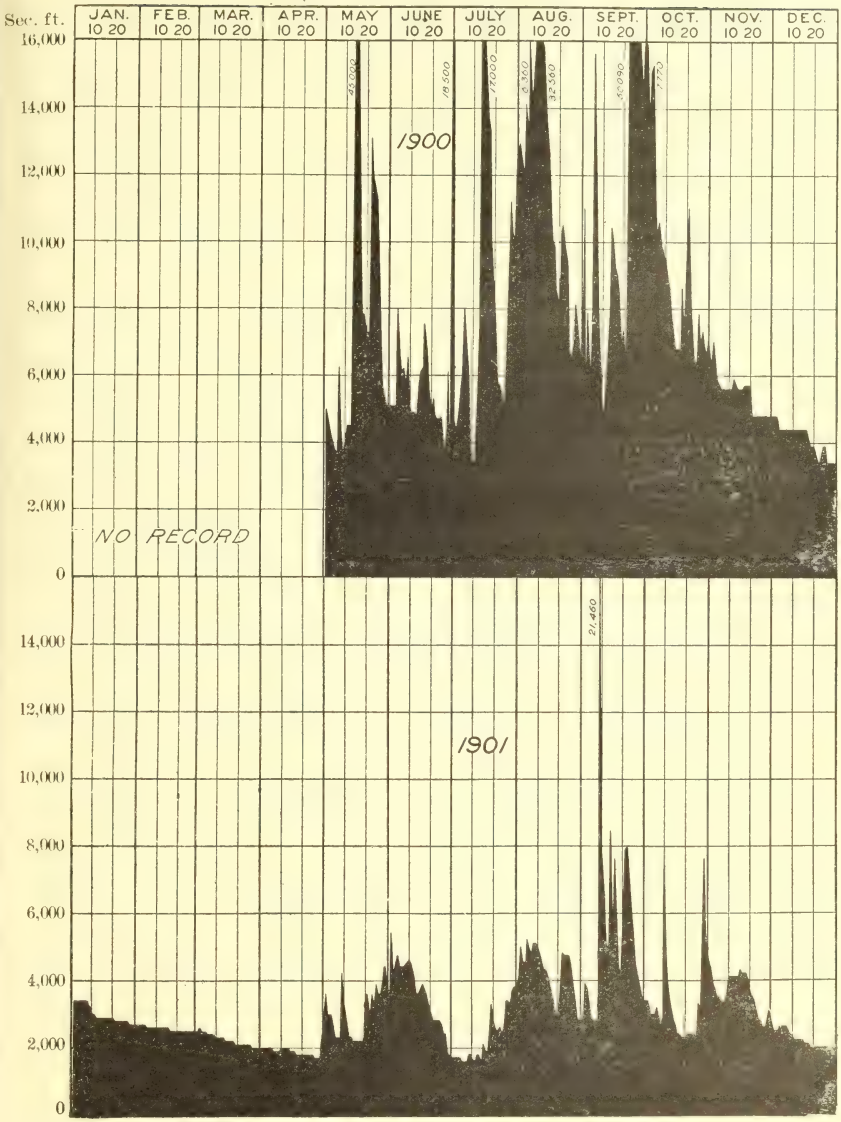


FIG. 52.—Discharge of Rio Grande near Eagle Pass, Tex., 1900–1901.

COLORADO RIVER DRAINAGE.

Considerable hydrographic work was carried on in the basin of Colorado River during the field season of 1901. Systematic stream measurements were made at all the stations maintained during the preceding year, with the exception of the station on Grand River at Grand Junction, Colo., which was abandoned. New stations were established during the year at Craig, Colo., on Yampa River; at

Meeker, Colo., on White River; at Whitewater, Colo., on Gunnison River; near Livingston, Ariz., on Tonto Creek, and on Salt River above the mouth of Tonto Creek. The latter two stations were established in connection with an investigation into the water supply for the proposed reservoir on Salt River. Similar investigations were conducted on Verde River during 1901. A detailed report of these investigations containing plans and estimates of the proposed dams has been published in Water-Supply Paper No. 73, entitled "Water Storage on Salt River, Arizona," by Arthur P. Davis, under whose direction the work was carried on.

Regular measurements were resumed at Greenriver station on Green River, in Wyoming, which station had been discontinued in March of the preceding year. The stations established on Duchesne River and tributaries during the fall of 1899 by C. C. Babb, in connection with his surveys for a water supply for the Uinta Indian Reservation, were maintained during 1901. Results of this investigation are given elsewhere in this report.

Two more investigations were carried on in the Colorado River Basin during the field season of 1901, one being a project for diverting water from Gunnison River into the valley of the Uncompahgre River for irrigating purposes, and the other consisting of a reconnaissance of Lower Colorado River for the purpose of discovering dam and reservoir sites.

GREEN RIVER.

Estimated monthly discharge of Green River at Greenriver, Wyo.

[Drainage area, 7,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	2,880	500	1,325	78,843	0.18	0.20
May	12,410	1,782	6,753	415,226	.91	1.05
June	10,214	3,405	5,416	322,274	.73	.81
July	4,202	1,845	2,751	169,152	.37	.43
August	2,455	905	1,411	86,759	.19	.22
September	905	500	632	37,607	.08	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 82; rating table on page 173 of same paper.

UINTA RIVER.

Estimated monthly discharge of Uinta River near Whiterocks, Utah.

[Drainage area, 218 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a] 140	8,608	0.64	0.74
February	[a] 140	7,775	.64	.67
March	[a] 150	9,223	.69	.80
April	[a] 179	10,651	.82	.92
May	[a] 684	42,058	3.14	3.62
June	[a] 355	21,124	1.63	1.82
July	[a] 251	15,433	1.15	1.33
August	[a] 242	14,880	1.11	1.28
September	[a] 193	11,484	.89	.99
October	[a] 163	10,022	.75	.86
November	[a] 142	8,450	.65	.73
December	[a] 147	9,039	.67	.77
The year	[a] 232	168,747	1.07	14.53

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 84; rating table on page 173 of same paper.

Estimated monthly discharge of Whiterocks River near Whiterocks, Utah.

[Drainage area, 114 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a] 50	3,074	0.44	0.51
February	[a] 50	2,777	.44	.46
March	[a] 50	3,074	.44	.51
April	[a] 74	4,403	4.65	.73
May	[a] 507	31,174	.45	5.13
June	[a] 179	10,651	1.57	1.75
July	[a] 101	6,210	.89	1.03
August	[a] 128	7,870	1.12	1.29
September	[a] 95	5,653	.83	.93
October	[a] 75	4,612	.66	.76
November	[a] 63	3,749	.55	.61
December	[a] 61	3,751	.54	.62
The year	[a] 119	86,998	1.05	14.33

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 85; rating table on page 173 of same paper.

Estimated monthly discharge of Uinta River at Fort Duchesne, Utah.

[Drainage area, 672 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 135	8,301	0.20	0.23
February			[a] 135	7,498	.20	.21
March	295	77	132	8,116	.20	.23
April	184	87	117	6,962	.17	.19
May	4,520	218	1,188	73,047	1.77	2.04
June	485	184	261	15,531	.39	.44
July	201	97	140	8,608	.21	.24
August	2,120	87	168	10,330	.25	.29
September	184	97	121	7,200	.18	.20
October	184	97	116	7,133	.17	.20
November	137	109	117	6,962	.17	.19
December			[a] 130	7,993	.19	.22
The year			[a] 230	167,681	.34	4.68

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 86; rating table on page 174 of same paper.

Estimated monthly discharge of Uinta River at Ouray School, Utah.

[Drainage area, 967 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			[a] 120	7,379	0.12	0.14
February			[a] 120	6,664	.12	.12
March		92	116	7,133	.12	.14
April	151	92	116	6,902	.12	.13
May	3,450	215	1,137	69,911	1.18	1.36
June	598	181	309	18,387	.32	.36
July	192	58	114	7,010	.12	.14
August	953	52	164	10,084	.17	.20
September	192	100	121	7,200	.13	.15
October	181	108	123	7,563	.13	.15
November	142	116	126	7,498	.13	.15
December			[a] 115	7,071	.12	.14
The year			[a] 223	162,802	.23	3.18

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 87; rating table on page 174 of same paper.

A. DUCHESNE RIVER 1 MILE ABOVE PRICE ROAD BRIDGE, UTAH.

B. DUCHESNE RIVER IMMEDIATELY ABOVE MOUTH OF UINTA RIVER, UTAH.

Estimated monthly discharge of Lake Creek, Utah, near mouth.

[Drainage area, 475 square miles.]

Month.	Mean discharge in second-feet.	Total in acre-feet.	Run-off.	
			Second-feet per square mile.	Depth in inches.
1901.				
January	[a]95	5,841	0.20	0.23
February	[a]95	5,276	.20	.21
March	[a]100	6,149	.21	.24
April	[a]132	7,855	.28	.31
May	[a]1,272	78,212	2.68	3.09
June	[a]556	33,084	1.17	1.31
July	[a]250	15,372	.53	.61
August	[a]255	15,679	.54	.62
September	[a]144	8,569	.30	.33
October	[a]132	8,116	.28	.32
November	[a]112	6,664	.24	.27
December	[a]110	6,764	.23	.27
The year	[a]271	197,581	.57	7.81

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 88 rating; table on page 174 of same paper.

Estimated monthly discharge of Duchesne River at Price road bridge, Utah.

[Drainage area, 2,746 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	.....	.....	[a]280	17,217	0.10	0.12
February	.....	.....	[a]280	15,550	.10	.10
March	.....	278	289	17,770	.11	.13
April	1,193	247	498	29,633	.18	.20
May	6,675	1,193	3,169	194,854	1.15	1.33
June	2,862	870	1,485	88,364	.54	.60
July	910	408	597	36,708	.22	.25
August	950	313	453	27,854	.16	.18
September	408	262	307	18,268	.11	.12
October	439	278	322	19,799	.12	.14
November	355	278	316	18,803	.12	.13
December	.....	.....	[a]300	18,446	.11	.13
The year	.....	.....	691	503,266	.25	3.43

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 89; rating table on page 174 of same paper.

ASHLEY CREEK.

This stream drains an area in northeastern Utah directly east of the Uinta River drainage. It flows southeasterly, entering Green River about 25 miles below the place where the latter stream crosses the State line between Colorado and Utah. About 7½ miles above the town of Vernal the creek leaves its mountainous area and enters what is known as Vernal Valley. This valley is approximately 20 miles long and 3 miles wide, its boundaries being sharply defined by the foothills. A large portion of the valley has been taken up by

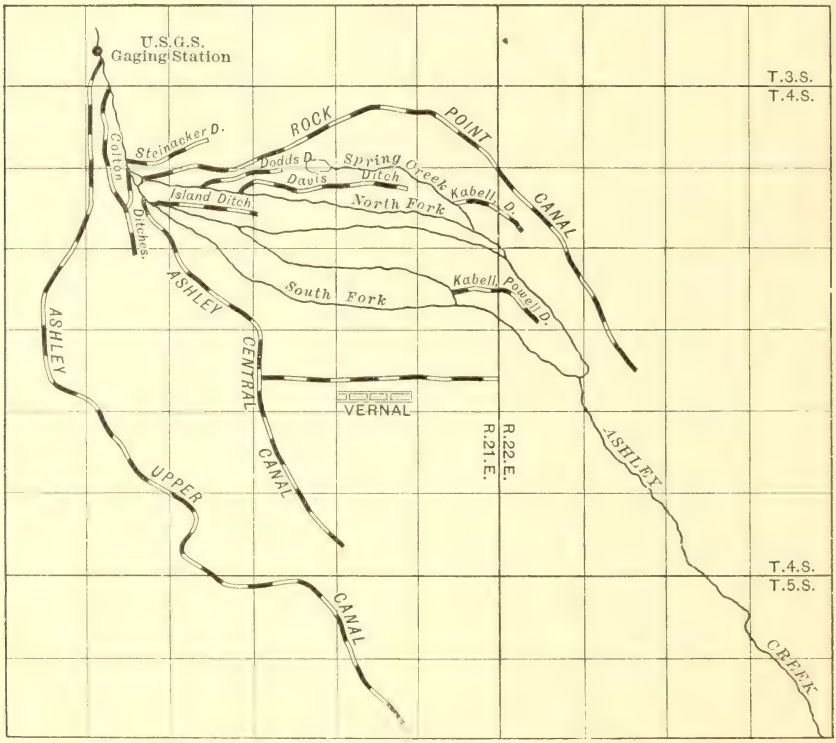


FIG. 53.—Canal system of Vernal Valley, Utah.

white settlers, and a considerable acreage is now under cultivation through irrigation.

There are three principal canals in use. Upper Ashley canal, on the west, built in 1882, covers 11,200 acres. The stock of the company is divided into 1,120 shares of a face value of $25 per share, and each share is for water to irrigate 10 acres. During the census year 1900 the area irrigated under this canal was 6,500 acres. Central Ashley canal, on the west side, built in 1880, covers 8,400 acres, 7,000 acres of which were irrigated in 1900. Each share is for sufficient water for 20 acres and is worth $50, or $2.50 per acre. Rock Point canal, on the east side, built in 1880, covers about 2,000 acres, 1,400

acres of which were irrigated in 1900. The stock of the company is divided into 250 shares of a face value of $10 per share, and each share is for water sufficient for $7\frac{1}{2}$ acres. There are a number of smaller canals lower down, the principal one being known as Island ditch, which controls 900 acres, 400 acres of which were irrigated in the census year 1900. The stock of the various canal companies is private property. A farmer, if entitled to a certain amount of water, is not supposed to rent or otherwise dispose of any portion of it, but it is often the case that he does.

By a decree of the district court dated November 17, 1897, the waters of Ashley Creek are divided as follows: Upper Irrigation Canal Company (Upper Ashley canal), $\frac{80}{81}$ of one-third of the discharge; Ashley Central Irrigation Canal Company, $\frac{86}{87}$ of one-third of the discharge; Rock Point and other canals (Union, Turner & Dodds, Island, Steinacker, and Colton), $\frac{75}{77}$ of one-third of the discharge; and Green River interveners the remainder. In accordance with this bill the water commissioner ordered all canal companies to install weirs so constructed as to bring the water to a quiet state 60 feet above the weirs. A weir 30 feet wide was placed in the river above the head of all canals, and weirs of the following dimensions were ordered placed in the canals, the sum of the width of the weirs being approximately the width of the river weir:

Weirs on Ashley Creek canals.

	Ft.	In.
Upper Ashley canal	9	10.4
Central Ashley canal, including Green River interveners (5.75 inches) and deducting Colton canal (3.70 inches)	10	.47
Union canal		7.11
Turner & Dodds ditch		11.52
Island ditch		17.41
Steinacker ditch		3.52
Rock Point canal	5	8.79
Colton ditch (decree of court $\frac{164}{2252}$, deed from Central Ashley canal $\frac{3}{97}$)		12.21

The two Ashley canals and the Rock Point canal are the only ones maintaining weirs. They are of the rectangular type, so constructed that each has two end contractions. No attempt is made to measure the quantity of water. When the creek is at its lowest stages, and it becomes necessary to divide the water among the canals, the flow into them is so regulated that exactly the same height of water is permitted to pass over each weir, the regulation stake, which is level with the crest of the weir, being placed a short distance above. As the lengths of the weirs correspond with the court decrees the amount of water is supposed to be in the required proportion. On account of the end contractions of the weirs of the two Ashley canals and the Rock Point canal, those ditches do not receive the same proportion of water for varying heights, as the reduction of length for end contractions is a function of the height of the water.

During the flood stages of the creek more water passes down it than the canals can carry, and therefore no attempt is then made to divide the water. It is only when lower stages of the creek are reached that the water is divided. No head gates are maintained in the canals, the flow being regulated by placing or removing rocks in the rough dam—an unsatisfactory method, of course.

The principal canals of the valley were measured twice during 1900, once in May, when the creek was in flood and a considerable amount of water was passing all canals and wasting into the stream below. The measurements, therefore, show approximately the maximum capacity of the various ditches. A second series of measurements was made in August, when the creek was at a low stage and after the water had been divided. The following table contains the results of the measurements made:

Discharge measurements in Vernal Valley, Utah.

Date.	Stream.	Locality.	Discharge.
1900.			*Sec. feet.*
May 28	Ashley Creek	Gaging station	776.0
May 29	Upper Ashley canal	Measuring weir	181.0
Do	Central Ashley canal	do	138.0
Do	Rock Point canal	Near head	25.0
Do	Steinacker canal	do	1.5
Aug. 21	Ashley Creek	Gaging station	40.0
Do	Upper Ashley canal	Measuring weir	12.0
Do	Central Ashley canal	do	10.0
Do	Rock Point canal	Near measuring weir	6.8

The population of Vernal Valley is 6,000. There are 38,000 acres of land on the valley tax rolls, only 25,000 acres of which are under ditch, according to the Twelfth Census. The following data are taken from the same authority:

The amount of land irrigated in 1900 was 17,471 acres. The average cost of a water right in the valley is $3 per acre, and the annual cost for maintenance is 15 cents per acre. An acre of land without water is valued at $1.25, but as soon as it is placed under ditch and is assured a good water supply the value increases to $30. The length of the irrigation season is six months—from April 1 to October 1.

The records of the flow of Ashley Creek at the gaging station in the canyon for the season of 1900 showed a total discharge of 56,225 acre-feet. The combined maximum capacity of the canals of the valley is 350 second-feet. May was the only month in 1900 in which there was more water than the canals could carry, as the average discharge for that month was 478 second-feet, or an excess of 128 second-feet. The latter amount represents an excess of 7,870 acre-feet. Subtracting this amount from the total discharge of the river for the period

will leave 48,355 acre-feet, the amount of water which approximately was spread over the area irrigated, 17,471 acres, during 1900. This is an average depth of 2.8 feet.

The discharge of 48,355 acre-feet for the six months represents a mean flow of 133 second-feet, or, expressed in other terms, the duty of water was 1 second-foot to 131 acres. The autumn is the season of low-water stages for the streams in this vicinity. The principal crops of the valley are alfalfa and oats. In the lower portion of the valley seepage water is now appearing in the river channels and is being used for irrigation purposes, thus increasing the duty of water in that section.

There is a voluntary observer of the Weather Bureau at Vernal, who has kept a continuous record for five years, the mean annual precipitation for that period being 9.38 inches. The precipitation in 1899 was 8.41 inches, and the mean temperature 46 degrees. There is no well-defined rainy season, but the principal rainfalls occur in June or July. The snowfall is generally light, the air usually dry, and strong winds are infrequent. The soil is a sandy loam. The mineral resources are said to be excellent in the surrounding mountains, deposits of gold, silver, and copper being worked to some extent. Coal is also found near by, and some deposits of uintaite of the asphaltum series. Transportation facilities are poor. The railroad is reached at Price, 140 miles distant, by way of Fort Duchesne.

East of Ashley Creek are two peculiar streams of the "disappearing" type, known as Little Brush Creek and Big Brush Creek. The main Brush Creek enters Green River 3 miles above the mouth of Ashley Creek. The peculiarity of these two forks is that their waters disappear and then reappear at various points along their courses. At one place Big Brush Creek enters a long, precipitous tunnel which has been only partly explored, and in which icicles and banks of ice are said to exist the year round.

As a result of a number of reports upon certain curious conditions said to exist in the basin of the Dry Fork, a tributary of Ashley Creek, a reconnaissance of the basin was made in August, 1901, by Mr. C. T. Prall, and from his report the following facts are taken:

The Dry Fork has its source in a lake in the Uinta Mountains about 35 miles northwest of Vernal. Its length is about 28 miles, 23 miles of which is in canyon varying in width from 500 feet to a half mile, and 5 miles is through a valley 1½ miles wide. The general course of the stream is southeast and the fall is heavy, at least 150 feet to the mile. It enters Ashley Creek about 8 miles above the town of Vernal. About midway the stream's length, or 10 miles northwest of Dry Fork post-office, a gaging was made on August 20, 1901, which gave a discharge of 96 second-feet. About 1,200 feet below that point occurs a pool or sink lying in a circular basin, whose banks, except on the

upstream side, are from 75 to 100 feet high. The stream enters this pool through several inlets. It is apparently bottomless, and the water in the larger end has a slow, circular motion, but whether this is caused by the incoming streams or by suction from below could not be determined. The only visible outlet from the pool is a narrow, rocky channel which has been widened, by blasting, in an effort to increase its flow. It was carrying about 10 second-feet when measured, but this water sank in a mile, or thereabouts.

Three miles below the pool the North Branch enters. One mile above its mouth 8 second-feet were flowing at the time of measurement, but the water vanished almost immediately upon reaching the main channel. Seven miles below the pool are located several springs, the upper and largest being a hole 25 feet in diameter. This spring was perfectly dry, but the lower ones were sending out 33 second-feet. A resident in the Dry Fork settlement since 1879 stated that only once before, to his knowledge, had these springs furnished water after the subsidence of the usual spring freshet. It was also stated that owing to recent rains the stream above the pool was higher than usual. Two miles below the springs, at the canyon's mouth, are located two ditches, but they had carried no water for several weeks. The stream bed was dry from the heads of the ditches to its mouth, a distance of 5 miles.

About 250 feet above the mouth of the Dry Fork a gaging of Ashley Creek showed 132 second-feet. About 400 feet below the mouth of the Dry Fork the discharge was 128 second-feet. A closer check than this would probably be impossible in view of the rather rough character of the creek's bed. One mile below the Dry Fork, at the regular gaging station, a discharge of 154 second-feet was found. The increase shown here is due to a ditch diverting water from the east side of Ashley Creek a short distance above the mouth of the Dry Fork and returning the water to the creek again above the gaging station. Two small ditches carrying a total of 3 second-feet are taken out of Ashley Creek between the Dry Fork and the gaging station.

The Dry Fork Valley comprises about 1,000 acres of arable land, all of which is under cultivation. Good crops are raised through use of spring flood waters, but much better results could be obtained by a more certain supply. However, a very small portion of the flow of the stream would suffice, leaving a large amount which could be used to excellent advantage in Ashley Valley. The visible supply in the two branches of the Dry Fork on August 21 was 104 second-feet, of which amount 33 second-feet found its way into the ditches. A flume 7 miles in length would carry the water below all known sinks, where it could be turned back into the stream and be subject to only the usual losses from seepage, etc. Even if 30 per cent were lost in trans-

mission, a stream capable of much good would still be available. A V-shaped flume was partly constructed some years ago, starting above the pool. It has fallen into disuse, but it is understood that plans are being made to rebuild it.

March 15, 1900, a gaging station, described in Water-Supply Paper No. 50, page 368, was established by C. T. Prall in the canyon of Ashley Creek, 7½ miles above the town of Vernal, and a short distance above the head of the upper canal. The gage is a vertical rod, painted white, fastened to the west side of the single pier of the wagon bridge. The bench mark is a 20-penny nail driven in the pier opposite the 4-foot mark. Results of measurements for 1901 are given in the following table:

Estimated monthly discharge of Ashley Creek near Vernal, Utah.

[Drainage area, 250 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	36	36	36	2,214	0.14	0.16
February	43	36	36	1,999	.14	.15
March	55	34	37	2,275	.15	.17
April	864	34	122	7,260	.49	.55
May	1,136	354	683	41,996	2.73	3.15
June	460	141	232	13,805	.93	1.04
July	141	72	100	6,149	.40	.46
August	932	72	149	9,162	.60	.69
September	131	72	96	5,712	.38	.42
October	72	55	62	3,812	.25	.29
November	63	48	58	3,451	.23	.26
December	55	48	52	3,197	.21	.24
The year	1,136	34	139	101,032	.55	7.58

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 83; rating table on page 173 of same paper.

GRAND RIVER.

Estimated monthly discharge of Grand River at Glenwood Springs, Colo.

[Drainage area, 5,838 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	810	550	688	42,180	0.12	0.14
February	970	630	746	41,430	.13	.15
March	970	727	837	51,465	.14	.16
April	7,100	727	1,888	112,343	.32	.36
May	22,895	6,420	13,797	848,529	2.36	2.72
June	15,660	9,620	12,174	724,404	2.09	2.33
July	10,765	2,090	4,833	297,170	.83	.96
August	3,630	1,350	1,907	117,072	.33	.38
September	1,460	840	1,045	62,182	.18	.20
October	970	870	917	56,445	.16	.18
November	935	810	879	52,364	.15	.17
December	935	630	788	48,452	.14	.16
The year	22,895	550	3,375	2,454,039	.58	7.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 92; rating table on page 174 of same paper.

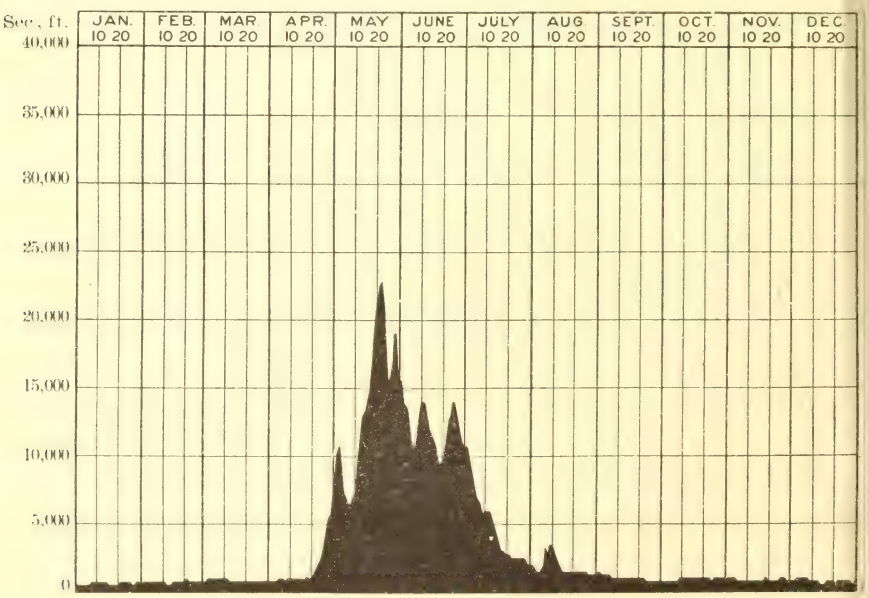


FIG. 54.—Discharge of Grand River at Glenwood Springs, Colo., 1901.

GUNNISON RIVER.

Estimated monthly discharge of Gunnison River at Iola, Colo.

[Drainage area, 2,298 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	2,442	426	910	54,148	0.39	0.44
May	7,402	2,137	3,756	230,949	1.55	1.79
June	3,686	2,289	2,892	172,086	1.24	1.38
July	2,289	663	1,151	70,773	.49	.56
August	1,118	496	676	41,750	.29	.33
September	663	300	399	23,742	.16	.18
October	361	300	322	19,799	.12	.14
November	361	300	310	18,446	.12	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 93; rating table on page 174 of same paper.

DOLORES RIVER.

Estimated monthly discharge of Dolores River at Dolores, Colo.

[Drainage area, 524 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March	555	82	178	10,945	0.34	0.39
April	2,386	82	878	52,245	1.68	1.87
May	3,086	1,371	2,085	128,201	3.98	4.59
June	1,686	810	1,206	71,524	2.30	2.46
July	627	141	266	16,355	.51	.59
August	343	100	174	10,698	.33	.38
September	220	19	42	2,499	.08	.09
October	37	19	26	1,599	.05	.06

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 95; rating table on page 174 of same paper.

LOS PINOS RIVER.

Estimated monthly discharge of Los Pinos River at Ignacio, Colo.

[Drainage area, 450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	1,166	109	452	26,896	1.00	1.12
May	1,569	735	1,026	63,086	2.28	2.63
June	887	645	763	45,402	1.70	1.90
July	555	83	226	13,896	.50	.58
August	825	95	202	12,420	.45	.52
September 1–26	.....	.....	[a]186	9,592	.41	[a].40

[a] Partial month.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 96; rating table on page 174 of same paper.

FLORIDA RIVER.

Estimated monthly discharge of Florida River near Durango, Colo.

[Drainage area, 136 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	339	21	110	6,545	0.81	0.90
May	625	248	377	23,181	2.77	3.20
June	326	41	172	10,235	1.27	1.42

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 96; rating table on page 174 of same paper.

VERDE RIVER.

Estimated monthly discharge of Verde River near McDowell, Ariz.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,500	259	351	21,575	0.059	0.067
February	6,613	394	1,859	103,249	.310	.323
March	2,863	211	895	55,018	.149	.172
April	221	155	185	10,988	.031	.034
May	185	125	140	8,606	.023	.027
June	164	59	105	6,222	.017	.019
July	1,680	29	210	12,916	.035	.040
August	3,000	163	627	38,561	.105	.121
September	172	45	93	5,514	.015	.017
October	730	82	134	8,210	.022	.025
November	336	187	245	14,571	.041	.046
December	288	247	268	16,485	.045	.052
The year	6,613	29	426	302,615	.071	.943

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 63, page 103.

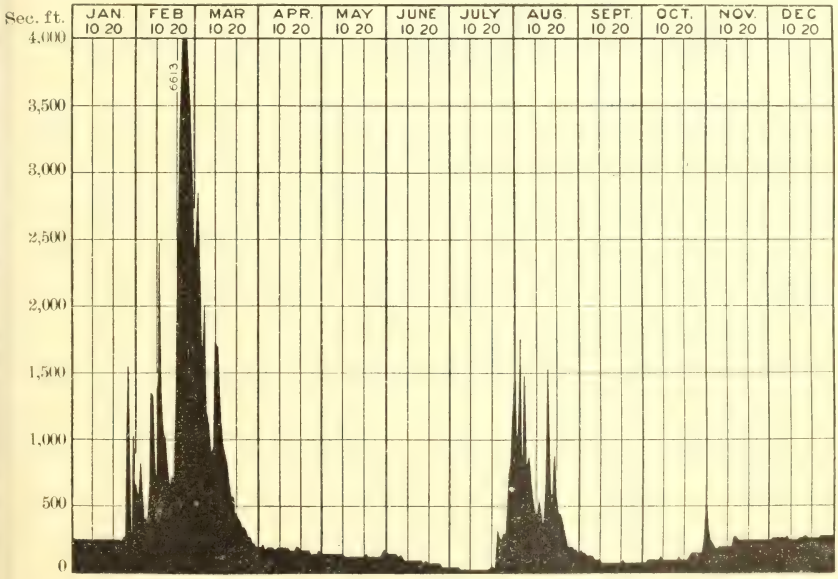


FIG. 55.—Discharge of Verde River near McDowell, Ariz., 1901.

SALT RIVER.

Estimated monthly discharge of Salt River at reservoir site, Arizona.

[Drainage area, 5,756 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January			454	27,945	0.08	0.09
February	4,172	928	2,414	134,047	.42	.44
March	3,468	740	1,423	87,472	.25	.29
April	1,562	740	1,050	62,442	.18	.20
May	1,267	462	735	45,203	.13	.15
June	508	147	288	17,262	.05	.06
July	3,556	71	346	21,296	.06	.07
August	2,221	207	529	32,504	.09	.10
September	670	123	309	17,907	.05	.06
October	215	117	152	9,334	.03	.03
November	215	183	189	10,629	.03	.03
December	195	180	190	11,663	.03	.03
The year			672	477,704	.11	1.55

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 99.

Estimated monthly discharge of Tonto Creek near Livingston, Ariz.

[Drainage area, 1,030 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	40	16	27	1,622	0.026	0.029
May	43	6	14	865	.014	.016
June	9	0	5	201	.005	.006
July	959	2	37	2,255	.036	.042
August	279	0	27	1,686	.026	.030
September	8	2	3	175	.003	.003
October	2	2	2	123	.002	.002
November	3	2	3	170	.003	.003
December	2	2	2	123	.002	.002

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 101.

Estimated monthly discharge of Salt River near McDowell, Ariz.

[Drainage area, 6,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,172	235	582	35,788	0.09	0.10
February	5,100	1,412	2,422	134,517	.39	.41
March	3,157	827	1,634	100,494	.26	.30
April 1–19 [a]			1,005	37,895	.16	.11
June	590	128	284	16,972	.05	.06
July			[b] 152	[b] 9,350	[b] .02	[b] .02
August	1,130	205	[b] 369	[b] 22,711	[b] .06	[b] .07
September	710	121	192	11,420	.03	.03
October	191	118	143	8,816	.02	.02
November	209	155	189	11,218	.03	.03
December	189	157	182	11,185	.03	.03

[a] No observations made from April 20 to June 1. [b] Estimated.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 102.

GILA RIVER.

Estimated monthly discharge of Gila River at San Carlos, Ariz.

[Drainage area, 13,455 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,330	110	199	12,236	0.0148	0.0171
February	2,080	450	1,079	59,925	.0802	.0835
March	1,070	155	446	27,423	.0332	.0383
April	155	5	53	3,154	.0039	.0044
May	8	5	5	307	.0004	.0005
June	5	0	3	178	.0002	.0002
July	4,200	0	368	22,627	.0273	.0315
August	3,050	10	536	32,957	.0398	.0459
September	8,500	2	250	14,876	.0186	.0208
October	1,000	2	91	5,595	.0068	.0078
November	680	125	232	13,805	.0172	.0192
December	125	100	109	6,702	.0081	.0093
The year	8,500	0	281	199,785	.0209	.2785

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 99.

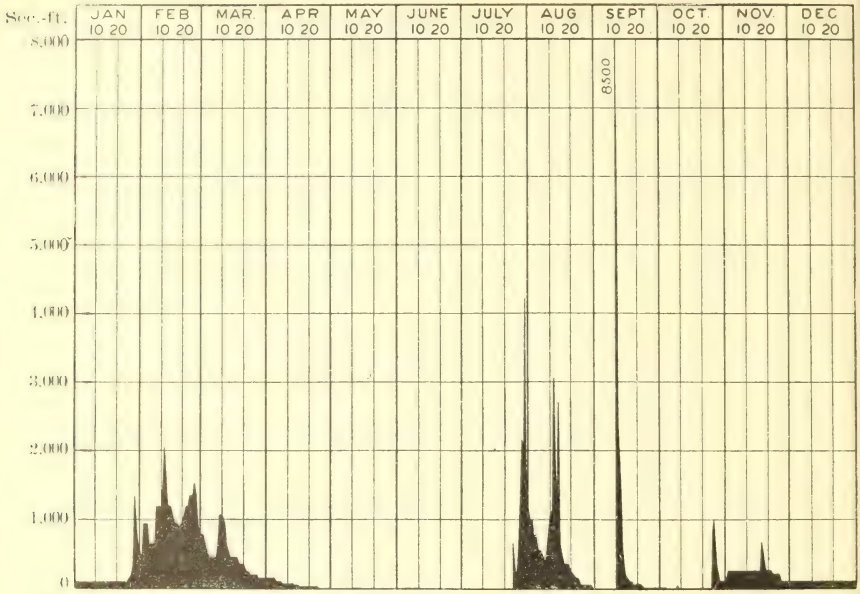


FIG. 56.—Discharge of Gila River at San Carlos, Ariz., 1901.

INTERIOR BASIN DRAINAGE.

Under this head is comprised the large extent of arid country which includes nearly the whole of Nevada, the northern and western parts of Utah, and small portions of California and Idaho. Having no outlet to the sea, the entire drainage of this vast basin is lost mainly through evaporation from the numerous lakes and sinks in which the waters of the rivers collect. During 1901 measurements were made of the streams draining into all of the principal lakes of the interior basin, with the exception of Walker River draining into Walker Lake.

In the Great Salt Lake drainage the following rivers were measured: Bear River and tributaries, Weber River, and Ogden River. In Utah Lake drainage, American Fork, Provo River, and Spanish Fork. In Sevier Lake drainage, Sevier River and its tributaries, the San Pitch and the Salina.

Humboldt River, draining into Humboldt sink, was measured at four places, viz, near Elko, near Golconda, and near Oreana, on the main stream, and at Mason's ranch, on the South Fork.

Truckee River, flowing into Lake Tahoe and thence into Pyramid Lake, is measured at Tahoe at the outlet of the lake, at the California-Nevada State line, and at Vista, Nev. Steamboat Creek, a tributary of the Truckee, is gaged at Steamboat Springs.

Carson River, the waters of which disappear in Carson sink, is measured at Empire, Nev. Its main tributaries, the East and West

forks, are gaged near Gardnerville, Nev., and at Woodfords, Cal., respectively.

A number of reservoir sites were surveyed in the Truckee River Basin during the season of 1901. Descriptions of these sites, together with estimates of cost of construction and of the amount of land to be irrigated, are published in Water-Supply Paper No. 68, entitled Water Storage in the Truckee River Basin, by L. H. Taylor, under whose direction the surveys were made.

The principal tributary of Honey Lake is Susan River. Measurements have been made on this stream during 1901 near Susanville, Cal., and on Willow Creek, a tributary, near Standish, Cal.

HUMBOLDT RIVER.

Estimated monthly discharge of Humboldt River, near Elko, Nev.

[Drainage area, 2,840 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	70	63	65	3,997	0.023	0.027
February	2,339	49	671	37,265	.236	.246
March	1,121	284	480	29,514	.169	.195
April	374	253	295	17,553	.104	.116
May	822	319	511	31,420	.180	.208
June	594	32	353	21,005	.124	.138
July	123	14	50	3,074	.018	.021
August	43	.5	12	738	.004	.005
September	18	.5	6	357	.002	.002
October	22	4	8	492	.003	.003
November	10	7	9	536	.003	.003
December	10	10	10	615	.004	.005
The year	2,339	0.5	206	146,566	.072	.969

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 104; rating table on page 174 of same paper.

Estimated monthly discharge of South Fork of Humboldt River at Mason's Ranch, Nev.

[Drainage area, 1,150 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	35	24	33	2,029	0.029	0.033
February	1,478	35	408	22,659	.355	.370
March	382	122	173	10,637	.150	.173
April	263	122	180	10,711	.157	.175
May	619	276	457	28,100	.397	.458
June	589	182	379	22,552	.330	.368
July	182	41	81	4,980	.070	.081
August	41	4	21	1,291	.018	.021
September	19	4	8	476	.007	.008
October	47	19	37	2,275	.032	.037
November	67	47	55	3,273	.048	.054
December	67	35	51	3,136	.044	.051
The year	1,478	4	157	112,119	.136	1.829

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 105; rating table on page 174 of same paper.

Estimated monthly discharge of Humboldt River near Golconda, Nev.

[Drainage area, 10,780 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	108	40	65	3,997	0.0060	0.0069
February	1,290	59	323	17,939	.0300	.0312
March	3,080	558	1,501	92,293	.1392	.1605
April	558	334	423	25,170	.0392	.0437
May	521	65	382	23,488	.0354	.0408
June	416	156	276	16,423	.0256	.0285
July	139	4	48	2,951	.0045	.0052
August	24	4	12	738	.0011	.0013
September	5	1	2	119	.0002	.0002
October	6	0.5	4	246	.0004	.0005
November	46	5	9	536	.0008	.0009
December	52	8	31	1,906	.0029	.0033
The year	3,080	0.5	256	185,806	.0238	.3230

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 106; rating table on page 175 of same paper.

Estimated monthly discharge of Humboldt River near Oreana, Nev.

[Drainage area, 13,800 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	205	60	113	6,948	0.008	0.009
February	430	99	222	12,329	.016	.017
March	2,616	301	1,318	81,041	.096	.111
April	986	330	587	34,929	.043	.048
May	511	167	317	19,492	.023	.027
June	167	99	133	7,914	.010	.011
July	150	60	108	6,641	.008	.009
August	88	21	39	2,398	.003	.003
September	21	10	17	1,012	.001	.001
October	274	21	48	2,951	.003	.003
November	38	26	30	1,785	.002	.002
December	78	32	51	3,136	.004	.005
The year	2,616	10	249	170,576	.018	.246

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 107; rating table on page 175 of same paper.

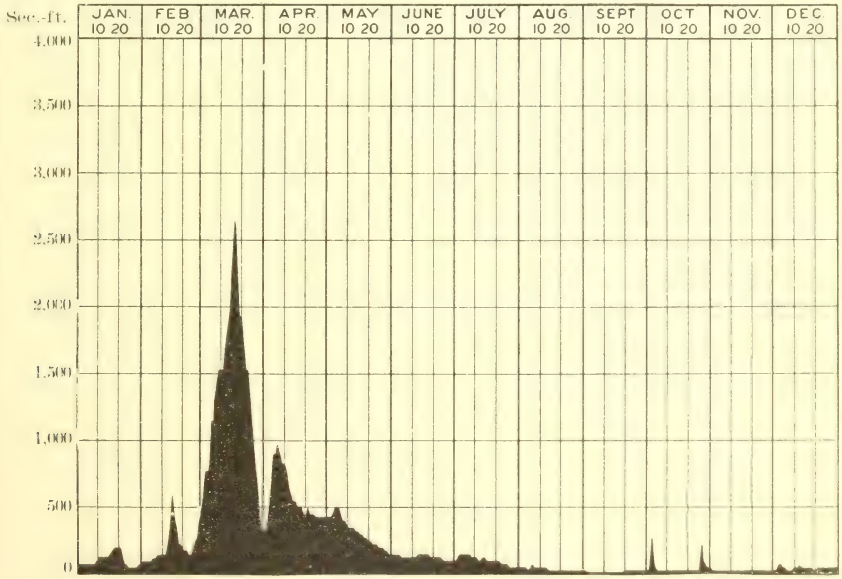


FIG. 57. Discharge of Humboldt River near Oreana, Nev., 1901.

TRUCKEE RIVER.

Estimated monthly discharge of Truckee River at Tahoe, Cal.

[Drainage area, 519 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches
1901.						
January	117	85	102	6,262	0.196	0.226
February	117	30	81	4,502	.156	.163
March	30	30	30	1,845	.058	.067
April	30	0	9	565	.018	.020
May	0	0	0	0	.000	.000
June	178	0	30	1,765	.058	.064
July	293	156	225	13,809	.433	.499
August	555	293	419	25,760	.803	.931
September	390	117	326	19,395	.628	.701
October	308	251	282	17,308	.542	.625
November	293	189	247	14,678	.475	.530
December	189	100	111	6,841	.214	.247
The year	555	0	155	112,730	.299	4.073

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 111; rating table on page 175 of same paper.

Estimated monthly discharge of Truckee River at Nevada-California State line.

[Drainage area, 955 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	559	230	314	19,308	0.329	0.379
February	3,435	247	1,082	60,092	1.133	1.176
March	2,280	732	1,280	78,708	1.340	1.544
April	2,505	613	1,476	87,829	1.545	1.728
May	4,370	1,508	2,478	152,370	2.595	2.992
June	2,505	989	1,595	94,910	1.670	1.862
July	1,194	421	686	42,181	.718	.828
August	795	349	486	29,884	.509	.588
September	559	247	472	28,086	.494	.552
October	559	247	470	28,900	.492	.566
November	613	383	469	27,908	.491	.549
December	1,194	247	445	27,347	.466	.536
The year	4,370	230	938	677,521	.982	13.300

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 112; rating table on page 175 of same paper.

Estimated monthly discharge of Steamboat Creek at Steamboat Springs, Nev.

[Drainage area, 123 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	56.0	3.0	7.6	467	0.061	0.071
February	72.0	3.0	15.6	866	.126	.132
March	20.5	5.0	10.8	664	.087	.101
April	11.5	3.0	7.7	458	.062	.069
May	29.5	11.5	21.4	1,316	.174	.200
June	39.0	17.0	29.6	1,761	.240	.268

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 114; rating table on page 175 of same paper.

Estimated monthly discharge of Truckee River at Vista, Nev.

Drainage area, 1,519 square miles.

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	1,505	418	661	40,644	0.435	0.502
February	4,213	418	1,486	82,529	.978	1.019
March	2,209	938	1,328	81,657	.874	1.008
April	1,942	747	1,380	82,117	.908	1.014
May	4,213	1,410	2,145	131,894	1.412	1.628
June	1,942	854	1,263	75,155	.831	.928
July	995	146	425	26,133	.280	.323
August	492	128	315	19,369	.207	.227
September	467	251	329	19,577	.217	.242
October	720	370	477	29,330	.314	.362
November	882	467	557	33,144	.367	.409
December	1,287	322	510	31,357	.336	.387
The year	4,213	128	906	652,906	.597	8.07

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 113; rating table on page 175 of same paper.

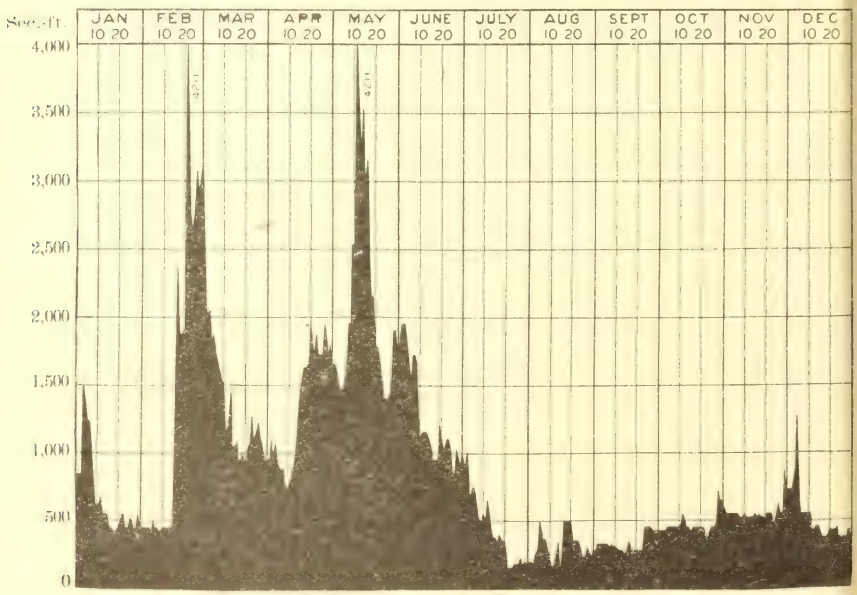


FIG. 58.—Discharge of Truckee River at Vista, Nev., 1901.

CARSON RIVER.

Estimated monthly discharge of East Fork of Carson River near Gardnerville, Nev.

[Drainage area, 381 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October			38	2,337	0.100	[a] 0.058
November	75	30	41	2,440	.108	.120
December	35	30	34	2,091	.089	.103
1901.						
January	86	14	34	2,091	.089	.103
February	2,267	14	664	36,877	1.743	1.815
March	927	219	464	28,531	1.218	1.256
April	927	261	582	34,632	1.527	1.704
May	3,162	856	1,822	112,033	4.782	5.513
June	2,008	1,141	1,492	88,780	3.916	4.369
July	1,512	313	741	45,562	1.945	2.242
August	626	85	259	16,026	.680	.789
September	220	85	139	8,271	.365	.407
October	271	102	137	8,424	.360	.415
November	332	122	196	11,663	.514	.574
December	1,213	134	280	17,217	.735	.847
The year	3,162	14	568	410,107	1.490	20.034

[a] Partial month.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 108; rating table on page 175 of same paper.

Estimated monthly discharge of West Fork of Carson River at Woodfords, Cal.

[Drainage area, 70 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October 18–31	----	----	44	1,222	0.63	0.33
November	60	37	48	2,856	.69	.77
December	71	37	53	3,259	.76	.87
1901.						
January	66	41	51	3,136	.73	.84
February	256	41	111	6,165	1.59	1.65
March	256	121	170	10,453	2.43	2.80
April	412	121	234	13,924	3.34	3.73
May	896	295	476	29,268	6.80	7.84
June	396	187	289	17,197	4.13	4.61
July	187	97	136	8,363	1.94	2.24
August	166	50	77	4,735	1.10	1.27
September	50	41	43	2,559	.61	.69
October	60	41	49	3,013	.70	.81
November	60	50	56	3,332	.80	.89
December	112	60	82	5,042	1.17	1.35
The year	896	41	148	107,187	2.11	28.72

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 109; rating table on page 175 of same paper.

Estimated monthly discharge of Carson River near Empire, Nev.

[Drainage area, 988 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
October			70	4,304	0.071	0.082
November	550	46	109	6,486	.110	.123
December	113	68	93	5,718	.094	.109
1901.						
January	772	40	115	7,071	.116	.134
February	2,470	40	645	35,822	.653	.682
March	1,001	478	634	38,984	.642	.740
April	1,420	329	700	41,653	.709	.790
May	3,791	924	1,994	122,606	2.018	2.328
June	2,304	853	1,422	84,615	1.438	1.605
July	1,084	167	468	28,777	.474	.546
August	297	40	126	7,748	.128	.147
September	70	25	39	2,321	.040	.044
October	213	70	113	6,948	.114	.132
November	297	189	197	11,722	.199	.222
December	758	213	311	19,122	.315	.363
The year	3,791	25	563	407,389	.570	7.733

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 111; rating table on page 175 of same paper.

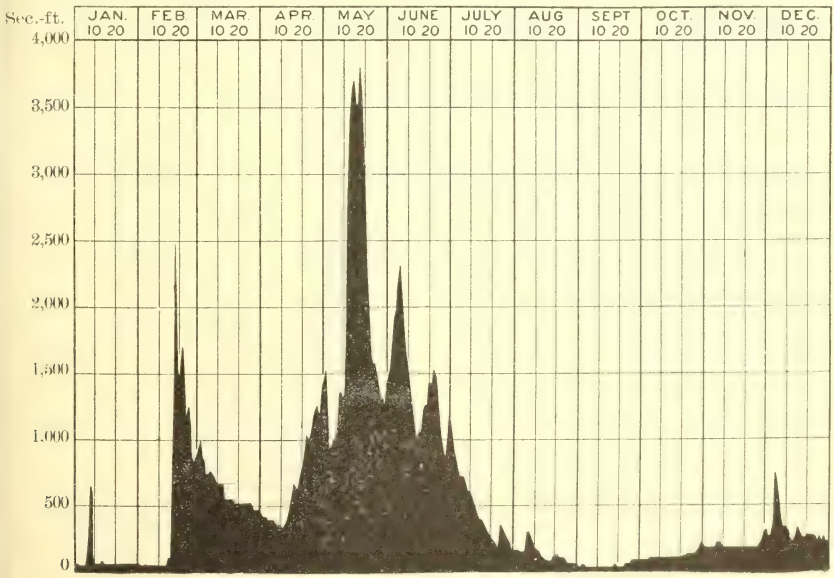


FIG. 59.—Discharge of Carson River near Empire, Nev., 1901.

SUSAN RIVER.

Estimated monthly discharge of Susan River near Susanville, Cal.

[Drainage area, 210 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	.....	.....	31	1,669	0.15	0.15
July	18	11	13	799	.06	.07
August	12	10	11	676	.05	.06
September	11	10	11	655	.05	.06
October	36	11	17	1,045	.08	.09
November	390	15	47	2,797	.22	.25
December	470	26	60	3,689	.29	.33
1901.						
January	52	36	43	2,644	.20	.23
February	1,070	36	308	17,105	1.47	1.53
March	770	197	363	22,320	1.73	1.99
April	730	134	371	22,076	1.77	1.97
May	590	168	420	25,825	2.00	2.31
June	156	15	56	3,332	.27	.30
July	24	9	18	1,107	.09	.10
August	13	5	10	615	.05	.06
September	9	4	6	369	.03	.03
October	16	7	10	615	.05	.06
November	101	10	19	1,131	.09	.10
December	470	11	61	1,783	.29	.33
The year	1,070	1	140	98,922	.67	9.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 116; rating table on page 175 of same paper.

BEAR RIVER.

Estimated monthly discharge of Bear River at Battlecreek, Idaho.

[Drainage area, 4,500 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	522	497	503	30,928	0.11	0.13
February	1,650	497	663	36,821	.15	.16
March	1,650	1,070	1,217	74,830	.27	.31
April	2,568	1,070	1,619	96,337	.36	.40
May	2,925	2,466	2,726	167,614	.61	.70
June	2,415	737	1,425	84,793	.32	.36
July	704	400	487	29,944	.11	.13
August	434	400	418	25,702	.09	.10
September	474	400	436	25,944	.10	.11
October	578	474	505	31,051	.11	.13
November	578	497	561	33,384	.12	.13
December	704	522	614	37,753	.13	.15
The year	2,925	400	931	675,101	.21	2.81

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 117; rating table on page 176 of same paper.

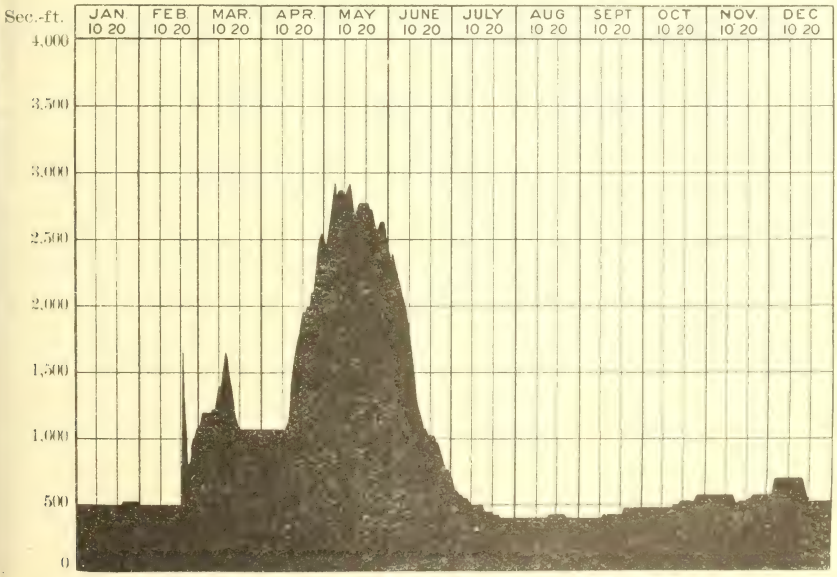


FIG. 60.—Discharge of Bear River at Battlecreek, Idaho, 1901.

Estimated monthly discharge of Logan River near Logan, Utah.

[Drainage area, 218 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	167	143	159	9,777	0.73	0.84
February	167	150	155	8,608	.71	.74
March	167	150	156	9,592	.72	.83
April	450	150	236	14,043	1.08	1.20
May	1,440	422	901	55,400	4.13	4.76
June	850	511	667	39,689	3.06	3.53
July 9–31			289	13,184	1.33	1.13
August	258	227	240	14,757	1.10	1.27
September	227	213	213	12,674	.98	1.09
October	213	188	197	12,113	.90	1.04

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66; rating table on page 176 of same paper.

Estimated monthly discharge of Blacksmith Fork at Hyrum, Utah.

[Drainage area, 286 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	124	108	115	7,071	0.40	0.46
February	128	108	113	6,276	.40	.42
March	147	112	119	7,317	.42	.48
April	147	112	132	7,855	.46	.51
May	514	112	187	11,498	.65	.75
June	347	147	187	11,127	.65	.73
July	147	128	133	8,178	.47	.54
August	147	128	134	8,239	.47	.54
September	128	120	122	7,261	.43	.48
October	293	120	131	8,056	.46	.53
November	120	120	120	7,141	.42	.47
December	120	112	119	7,317	.42	.48
The year	514	108	134	97,336	.47	6.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 119; rating table on page 176 of same paper.

Estimated monthly discharge of Bear River near Collinston, Utah.

[Drainage area, 6,000 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,550	915	1,239	76,183	0.21	0.24
February	2,880	1,105	1,555	86,354	.26	.27
March	2,880	1,700	2,032	124,943	.34	.39
April	3,575	1,700	2,399	142,750	.40	.45
May	4,950	3,575	4,469	274,788	.74	.85
June	3,640	1,025	2,029	120,734	.34	.38
July	987	415	686	42,180	.11	.13
August	717	415	574	35,294	.10	.12
September	915	635	724	43,081	.12	.13
October	1,105	880	1,006	61,857	.17	.20
November	1,232	1,025	1,144	68,073	.19	.21
December	1,405	1,025	1,197	73,600	.20	.23
The year	4,950	415	1,588	1,149,837	.27	3.60

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Pap e No, 66, page 120; rating table on page 176 of same paper.

WEBER RIVER.

Estimated monthly discharge of Weber River near Uinta, Utah.

[Drainage area, 1,600 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	263	263	263	15,171	0.16	0.18
February	1,655	263	681	37,821	.43	.45
March	1,865	500	707	43,472	.44	.51
April	1,970	500	948	56,410	.59	.66
May	2,425	1,235	1,981	121,807	1.24	1.43
June	1,235	440	712	42,367	.45	.50
July	380	110	207	12,728	.13	.15
August	320	110	200	12,297	.13	.15
September	210	210	210	12,496	.13	.15
October	320	263	272	16,725	.17	.20

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 122; rating table on page 176 of same paper.

UTAH LAKE DRAINAGE.

Estimated monthly discharge of Spanish Fork near Mapleton, Utah.

[Drainage area, 670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	188	75	132	7,855	0.20	0.22
July	75	54	56	3,443	.08	.09
August	54	45	53	3,259	.08	.09
September	86	54	61	3,630	.09	.10
October	75	54	63	3,874	.09	.10
November	86	54	74	4,403	.11	.12
December	86	36	58	3,566	.09	.10
1901.						
January	200	15	41	2,521	.06	.07
February	372	15	91	5,054	.14	.15
March	141	75	97	5,964	.14	.16
April	224	86	131	7,795	.20	.22
May	385	176	271	16,663	.40	.46
June	188	86	133	7,914	.20	.22
July	86	64	77	4,735	.10	.12
August	164	64	99	6,087	.15	.17
September	86	75	75	4,463	.10	.11
October	119	75	82	5,042	.12	.14
November	97	75	82	4,879	.12	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 123; rating table on page 176 of same paper.

Estimated monthly discharge of Provo River near Provo, Utah.

[Drainage area, 640 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	353	279	314	19,307	0.49	0.56
February	1,658	258	471	26,158	.74	.77
March	411	302	333	20,475	.52	.60
April	788	302	392	23,326	.61	.68
May	2,093	587	1,181	72,617	1.85	2.13
June	875	224	399	23,742	.62	.69
July	240	224	239	14,696	.37	.43
August	240	224	238	14,634	.37	.43
September	240	240	240	14,281	.38	.42
October	302	240	257	15,802	.40	.46
November 1–16	279	279	279	8,854	.44	.26

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 123; rating table on page 176 of same paper.

Estimated monthly discharge of American Fork near American Fork, Utah.

[Drainage area, 66 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
June	213	54	111	6,016	1.68	1.87
July	67	34	45	2,767	.68	.78
August	27	23	26	1,599	.39	.45
September	43	23	26	1,547	.39	.44
October	34	27	30	1,845	.45	.52
November	34	27	29	1,726	.44	.49
December	34	27	33	2,029	.50	.58
1901.						
January	34	34	34	2,091	.52	.60
February	43	27	36	1,999	.55	.57
March	43	34	36	2,213	.55	.59
April 10–30			125	5,206	1.89	1.48
May 1–18			582	20,779	8.82	5.90

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 124; rating table on page 176 of same paper.

SEVIER RIVER.

Estimated monthly discharge of Salina Creek near Salina, Utah.

[Drainage area, 255 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	27.0	15.0	19.6	1,205	0.077	0.089
February	24.7	15.0	19.4	1,088	.076	.079
March	21.0	13.5	14.6	898	.057	.066
April	33.7	15.0	22.9	1,363	.090	.100

NOTE.—Gage heights for 1901 are given in Water-Supply Paper No. 66, page 125.

Estimated monthly discharge of San Pitch River near Gunnison, Utah.

[Drainage area, 836 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	15	9	12	738	0.014	0.016
February	37	9	16	889	.019	.020
March	21	9	13	774	.016	.018
April 7–30			35	2,083	.042	.047
May	125	51	92	5,657	.110	.127
June	95	65	77	4,582	.092	.103
July	71	15	45	2,767	.054	.062
August	25	15	18	1,107	.022	.025
September	15	10	14	833	.017	.019
October	19	14	14	861	.017	.020
November	14	10	13	774	.016	.018
December	13	12	12	738	.014	.016
The year	125	9	30	21,803	.036	.491

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 125; rating table on page 176 of same paper.

Estimated monthly discharge of Sevier River near Gunnison, Utah.

[Drainage area, 3,986 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	.....	.....	118	7,255	0.029	0.033
February	164	94	125	6,942	.031	.032
March	81	29	56	3,443	.014	.016
April	74	19	45	2,678	.011	.012
May	239	51	122	7,501	.031	.036
June	129	8	41	2,440	.010	.011
July	21	5	9	553	.002	.002
August	59	14	24	1,476	.006	.006
September	17	9	12	714	.003	.003
October	12	7	8	476	.002	.002
November	41	17	34	2,023	.009	.009
December	154	41	81	4,980	.020	.023
The year	239	5	56	40,481	.014	.185

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 126; rating table on page 176 of same paper.

COLUMBIA RIVER DRAINAGE.

Next to the Colorado, Columbia River is the largest river in the arid region, its drainage basin including parts of Washington, Oregon, Idaho, and Montana and a large area in Canada. The Columbia and its numerous tributaries are of great importance, offering good sites for water-power development and an abundance of water for irrigation, while the main river is navigable for a considerable distance. But little has been accomplished at the present time in developing either of these resources.

In the following pages is published a report on the irrigation development in the valley of Snake River, the most important tributary of the Columbia, by D. W. Ross, State engineer of Idaho.

During 1901 gaging stations were maintained on the following tributaries of the Columbia: On Missoula, Blackfoot, and Bitterroot rivers near Missoula, Mont.; on Snake River at Montgomery Ferry, near Minidoka, Idaho; on Boise River, near Boise, Idaho; on Weiser River near Weiser, Idaho; on Spokane River at Spokane, Wash.; on Naches River near North Yakima, Wash.; on Yakima River at Union Gap and at Kiona, Wash.; on Palouse River, near Hooper,

Wash.; and on Umatilla River at Gibbon, Oreg., the results of measurements of which are given in the following pages.

MISSOULA RIVER.

Estimated monthly discharge of Blackfoot River near Bonner, Mont.

[Drainage area, 2,465 square miles.]

Month.	Discharge in second-feet.			Total in acre feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,060	550	673	41,381	0.27	0.31
February	1,310	450	580	32,212	.24	.25
March	3,988	550	1,017	62,533	.41	.47
April	2,950	585	1,186	70,572	.48	.54
May	12,302	3,899	8,552	525,842	3.47	4.00
June	7,676	2,650	3,698	220,046	1.50	1.67

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 130; rating table on page 177 of same paper.

Estimated monthly discharge of Missoula River at Missoula, Mont.

[Drainage area, 5,960 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
March			2,090	128,509	0.35	0.40
April 1-10, 13-30			2,601	154,770	.44	.47
May	20,200	7,300	15,156	931,906	2.54	2.93
June	14,450	5,150	7,458	443,782	1.25	1.39
July	4,650	1,690	2,815	173,026	.47	.54
August	1,625	980	1,300	79,933	.22	.25
September	1,625	980	1,415	84,198	.24	.27
October	1,625	1,430	1,472	90,510	.25	.29
November	1,625	1,365	1,478	87,947	.25	.28
December 1-10			1,413	27,794	.24	.09

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 131; rating table on page 177 of same paper.

A. TWIN FALLS OF SNAKE RIVER, IDAHO.

B. LOCATION OF DAM SITE NEAR TWIN FALLS, IDAHO.

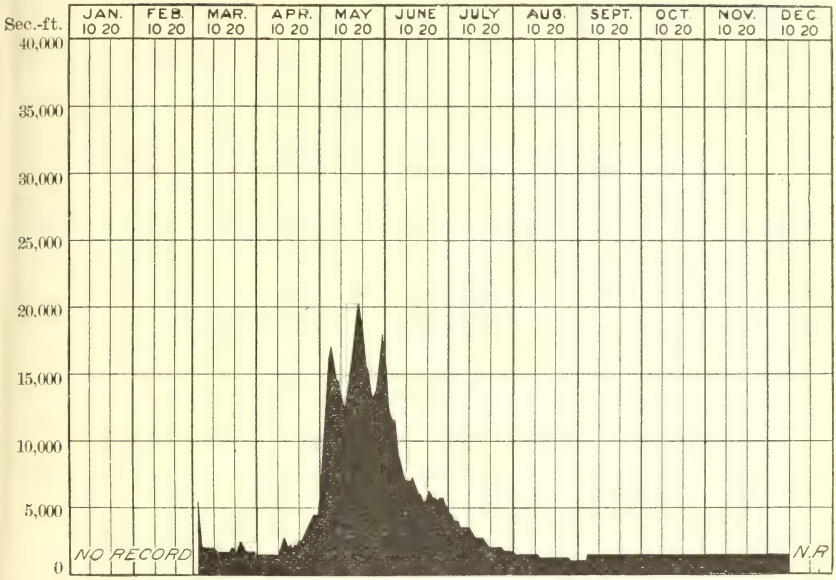


FIG. 61.—Discharge of Missoula River at Missoula, Mont., 1901.

Estimated monthly discharge of Bitterroot River at Missoula, Mont.

[Drainage area, 3,260 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	.....	.....	1,360	83,623	0.42	0.49
February	.....	.....	1,401	77,808	.43	.45
March	2,750	1,390	1,691	103,976	.52	.60
April (twenty-one days)	.....	.....	1,866	81,425	.57	.51
May	18,375	7,210	11,025	67,790	3.38	3.90
June	11,700	3,050	5,020	298,711	1.54	1.72
July	3,650	1,225	2,667	163,980	.82	.95
August	1,200	940	995	61,180	.31	.36
September	1,320	940	1,130	67,507	.35	.39
October	1,250	1,080	1,157	71,141	.36	.42
November	1,175	1,100	1,149	68,370	.35	.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 132.

SPOKANE RIVER.

Estimated monthly discharge of Spokane River at Spokane, Wash.

[Drainage area, 4,005 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,824	7,738	9,887	607,928	2.47	2.85
February	9,838	5,172	7,289	404,811	1.82	1.89
March	19,706	10,815	14,843	912,660	3.71	4.28
April	13,019	9,565	11,143	663,054	2.79	3.11
May	22,711	13,324	19,901	1,223,665	4.97	5.74
June	20,054	9,565	13,513	804,079	3.38	3.77
July	9,295	4,241	6,441	396,042	1.61	1.86
August	4,141	2,767	3,263	200,634	.82	.95
September	2,682	2,517	2,564	152,569	.64	.71
October	2,600	2,278	2,461	151,321	.62	.71
November	4,141	2,356	2,806	166,969	.70	.78
December	5,389	3,946	4,593	282,413	1.15	1.33
The year	22,711	2,278	8,225	5,966,145	2.06	27.98

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 133; rating table on page 177 of same paper.

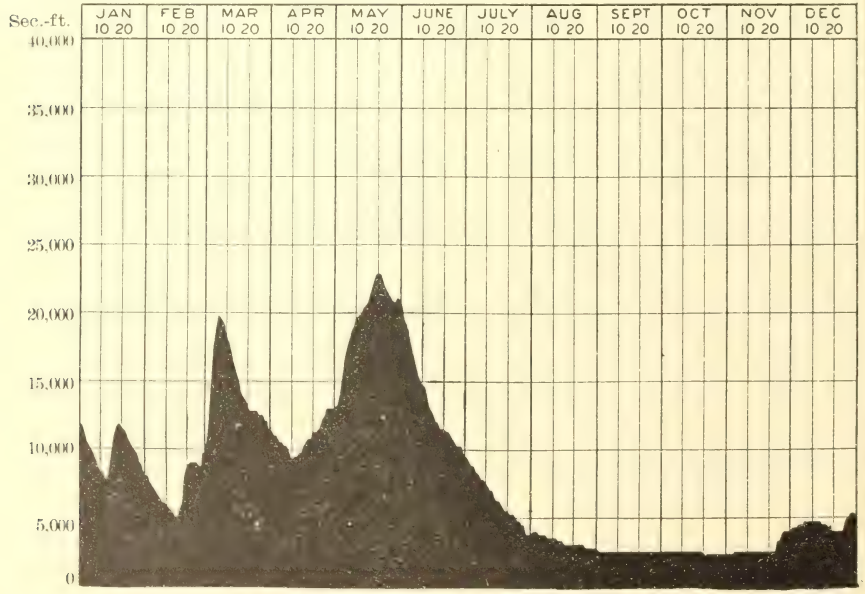


FIG. 62.—Discharge of Spokane River at Spokane, Wash., 1901.

SHOSHONE FALLS ON SNAKE RIVER, IDAHO.

SNAKE RIVER.

Estimated monthly discharge of Boise River near Boise, Idaho.

[Drainage area, 2,450 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,430	1,130	1,280	78,704	0.52	0.60
February	4,380	1,095	1,756	97,523	.72	.75
March	4,604	2,180	2,892	177,822	1.18	1.36
April	8,636	2,070	5,056	300,853	2.06	2.30
May	12,668	7,516	10,106	621,394	4.13	4.76
June	7,740	2,720	4,789	284,965	1.95	2.18
July	2,880	1,060	1,878	115,474	.77	.89
August	1,060	740	846	52,141	.35	.40
September	990	770	833	49,567	.34	.38
October	1,095	860	910	55,954	.37	.43
November	1,200	860	933	55,517	.38	.42
December	2,180	830	1,233	75,814	.50	.58
The year	12,668	740	2,708	1,965,728	.11	15.05

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 128; rating table on page 176 of same paper.

Estimated monthly discharge of Weiser River near Weiser, Idaho.

[Drainage area, 1,670 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,800	375	945	58,106	0.57	0.66
February	7,137	470	1,921	106,678	1.15	1.20
March	6,230	1,425	2,964	182,249	1.77	2.04
April	3,530	1,330	2,523	150,129	1.51	1.68
May	5,150	2,585	3,935	241,958	2.36	2.73
June	2,585	585	1,304	77,593	.78	.87
July	585	250	363	22,320	.22	.25
August	215	39	67	4,120	.04	.05
September	87	47	71	4,225	.04	.04
October	137	96	115	70,712	.07	.08
November	330	137	191	11,365	.11	.12
December	1,330	250	525	32,281	.31	.36
The year	7,137	39	1,244	961,736	.74	10.08

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 129; rating table on page 176 of same paper.

YAKIMA RIVER.

Estimated monthly discharge of Naches River near North Yakima, Wash.

[Drainage area, 1,000 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	4,030	910	1,559	95,859	1.56	1.80
February	4,600	830	1,621	90,026	1.62	1.69
March	9,100	1,690	3,427	210,718	3.43	3.96
April	2,780	1,550	2,199	130,850	2.20	2.46
May	8,800	3,250	5,628	346,052	5.63	6
June	6,700	2,570	4,026	239,564	4.03	[illegible]
July	2,780	1,090	1,937	119,101	1.94	[illegible]
August	1,090	430	683	41,996	.68	.78
September	470	390	405	24,099	.41	.46
October	430	370	380	23,365	.38	[illegible]
November	6,400	430	1,101	65,514	1.10	1.23
December	4,030	750	1,600	98,380	1.60	1.84
The year	9,100	370	2,047	1,485,524	2.05	27.89

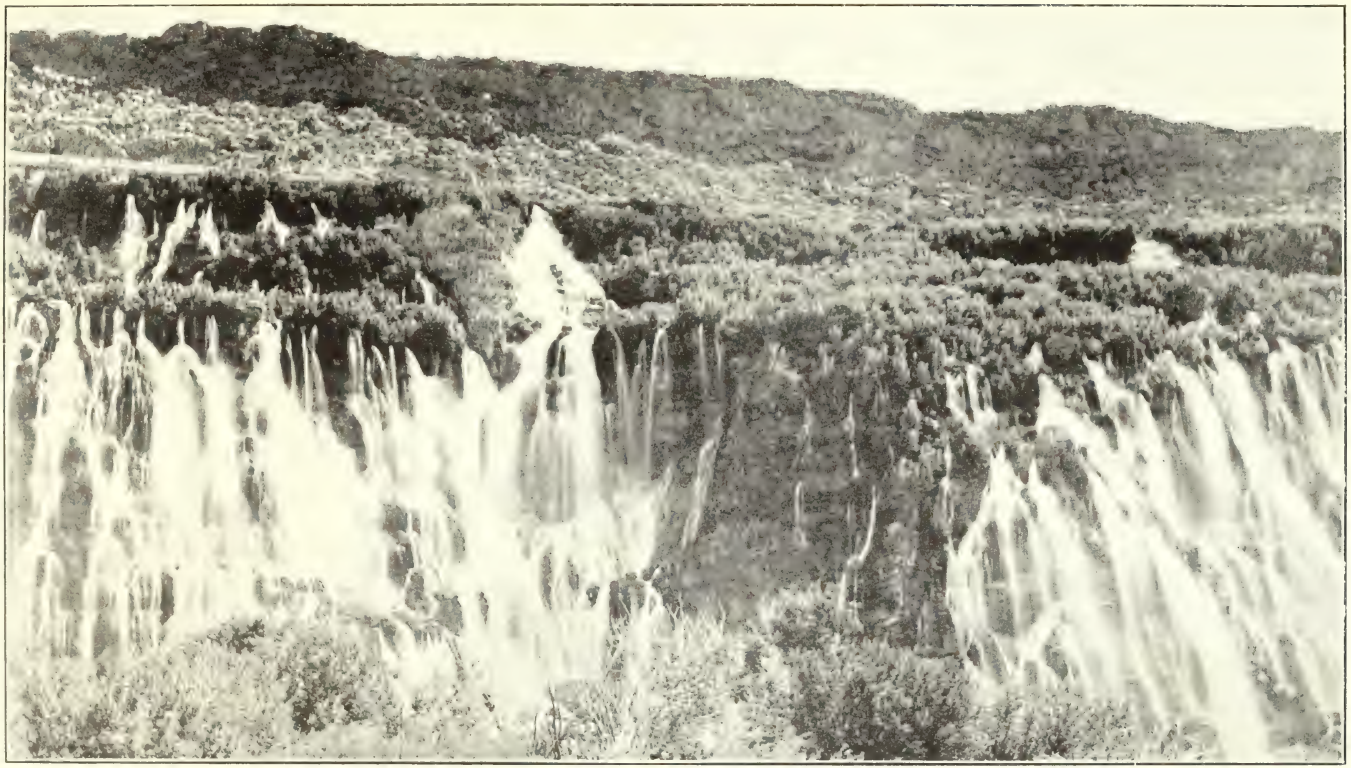
NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 134; rating table on page 177 of same paper.

Estimated monthly discharge of Yakima River at Union Gap, Wash.

[Drainage area, 3,300 square miles.]

Month.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	8,650	2,600	4,371	268,762	1.32	1.52
February	10,750	1,950	3,720	206,598	1.13	1.18
March	20,900	4,250	8,356	513,790	2.53	2.92
April	6,300	4,000	5,272	313,706	1.60	1.79
May	18,100	6,900	11,482	706,001	3.48	4.05
June	13,200	6,300	8,713	518,460	2.64	2.95
July	6,300	2,600	4,508	277,186	1.37	1.58
August	2,425	1,050	1,544	94,937	.47	.54
September	1,250	850	1,023	60,873	.31	.35
October	1,050	750	895	55,031	.27	.31
November	5,100	850	2,710	161,256	.82	.92
December	12,500	2,600	5,800	356,628	1.76	1.96
The year	20,900	750	4,866	3,533,228	1.48	20.07

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 135; rating table on page 177 of same paper.



THOUSAND SPRINGS ON SNAKE RIVER, IDAHO.

Estimated monthly discharge of Yakima River at Kiona, Wash.

[Drainage area, 5,230 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
January	13,545	4,935	6,886	423,404	1.32	1.52
February	14,745	3,592	6,299	349,828	1.20	1.25
March	24,045	6,995	11,779	724,263	2.26	2.61
April	8,782	5,833	7,420	441,521	1.42	1.58
May	20,745	8,472	14,037	863,101	2.68	3.09
June	15,345	5,228	8,773	522,030	1.68	1.87
July	5,150	1,832	3,476	213,731	.66	.76
August	1,769	525	1,053	64,746	.20	.23
September	519	465	481	28,620	.09	.10
October	917	525	643	39,537	.12	.14
November	6,248	940	3,202	190,532	.61	.68
December	9,570	1,769	4,316	265,381	.83	.96
The year	24,045	465	5,697	4,126,694	1.09	14.79

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 136; rating table on pape 177 of same paper.

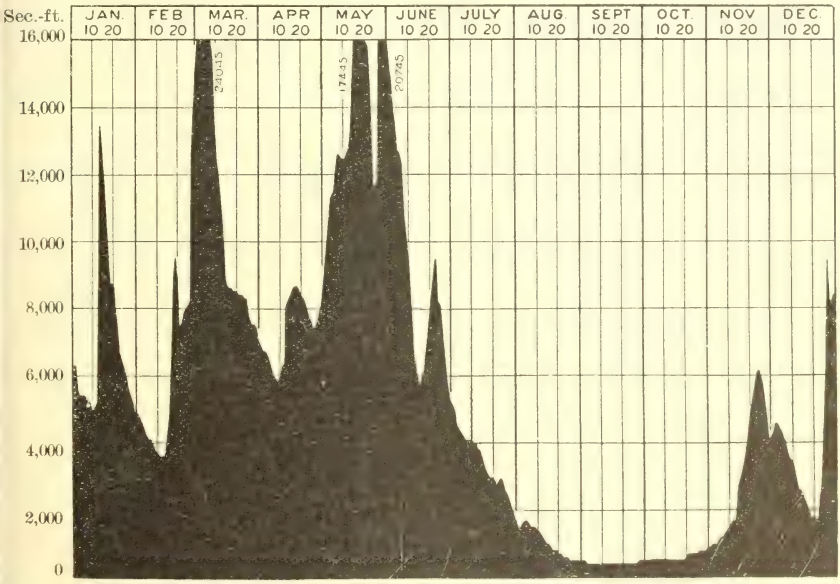


FIG. 63.—Discharge of Yakima River at Kiona, Wash., 1901.

DISCHARGE MEASUREMENTS OF ARTESIAN WELLS IN MOXEE VALLEY NEAR NORTH YAKIMA, WASH.[a]

No. 1.—Clarke's No. 1 (Pecks), sec. 6, T. 12, R. 20. Weir measurement, April 20, 1899; discharge, 1.435 second-feet.

This well was closed in December, 1900, and partly opened in April. Approximate measurement, with Price meter in flume, April 11, 1901, discharge, 1.34 second-feet. Barom. el., 1,049.

No. 2.—Clarke's No. 2, NE. ¼ SW. ¼ sec. 31, T. 13, R. 20. Weir measurement, March 3, 1899, 1,046 second-feet.

This well remained open during the winter. A measurement over an 18-inch weir, April 11, 1901, gave a discharge of 0.52 second-foot. Barom. el., 1,085.

No. 2a.—Clarke's No. 2a, NE. ¼ SW. ¼ sec. 31, T. 13, R. 20. Weir measurement, March 3, 1899, 0.469 second-foot.

This well remained open during the winter. A weir measurement, April 11, 1901, gave a discharge of 0.15 second-foot. Barom. el., 1,076.

No. 3.—Meigs, NW. ¼, SE. ¼, sec. 32, T. 13, R. 20. Discharge 18 cubic feet per minute.

This well has ceased to flow and is now abandoned.

No. 4.—Yakima Land Company, No. 4, sec. 4, T. 12, R. 20. No flow.

Well abandoned.

No. 5.—Yakima Land Company, No. 1, sec. 3, T. 12, R. 20. No flow.

Well abandoned.

No. 6.—Yakima Land Company, No. 3, sec. 3, T. 12, R. 20. Original yield estimated at 30 cubic feet per minute. No flow.

Well abandoned.

No. 7.—Bradford (now Hill), sec. 9, T. 12, R. 20. Measurement over 2-foot weir, March 19, 1901, gave a discharge of 0.904 second-foot.

No. 8.—Dickson, sec. 8, T. 12, R. 20. Yield unknown.

Abandoned since December 1, 1900.

No. 9.—Gano, sec. 8, T. 12, R. 20. No measurement obtainable. Partly shut down from December 1, 1900. April 1, 1901, still partly closed.

No. 10.—Eilens, SE. ¼ NE. ¼ sec. 7, T. 12, R. 20. Measurement made March 23, 1901, showed a discharge of 0.13 second-foot.

This well has been closed down since the summer of 1900. Barom. el., 995 feet. Cased 300 feet.

No. 11.—Longevin, sec. 8, T. 12, R. 20. Measurement on April 9, 1901, gave a discharge of 0.4 second-foot. Barom. el., 995.

No. 12.—Haines (Patterson), sec. 8, T. 12, R. 20. Measurement on March 22, 1901, gave a discharge of 0.984 second-foot.

No. 13.—Spratt (Sauvé), sec. 8, T. 12, R. 20. Weir measurement made March 22, 1901, gave discharge of 0.475 second-foot.

There is said to be 65 feet of sandstone below the first flow. The well was closed September 15, 1900, to be opened April 1, 1901.

No. 14.—Steinweg No. 1, SE. ¼ SE. ¼ sec. 10, T. 12, R. 20. A weir measurement on July 21, 1899, gave a discharge of 0.312 second-foot.

The well has ceased to flow and is abandoned.

No. 15.—Steinweg No. 2, sec. 10, T. 12, R. 20. A weir measurement, July 21, 1899, gave a discharge of 0.104 second-foot.

The well has ceased to flow and is abandoned. (Water rises to within 2 feet of the surface.)

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[a] As reported by Sydney Arnold, April 18, 1901. (See also Water-Supply Paper No. 55 on the Geology and Water Resources of Yakima County, Wash., by George Otis Smith.)

No. 16.—Steinweg No. 3, sec. 10, T. 12, R. 20. A weir measurement, July 21, 1899, gave a discharge of 0.1312 second-foot.

The well is now abandoned, having ceased to flow.

No. 17.—Yakima Land Company, sec. 14, T. 12, R. 20. No flow; well is abandoned. Seventy-five feet of the bore is in rock.

No. 18.—Ellens, SW. ¼ SE. ¼ sec. 5, T. 12, R. 20. Discharge, August, 1898, by weir measurement, 1.9 second-feet; March 26, 1891, approximate measurement by current meter, 2 second-feet. This is the largest in the valley. The well was closed down during the winter of 1900–1901.

No. 19.—Regimbau, SW. ¼ SE. ¼ sec. 5, T. 12, R. 20. Approximate measurement, with Price current meter, April 10, 1901, gave a discharge of 1.09 second-feet.

No. 20.—Buwalda, NE. ¼ SW. ¼ sec. 32, T. 13, R. 20. A weir measurement on March 3, 1899, gave a discharge of 0.8 second-foot; and on April 10, 1901, a discharge of 0.05 second-foot. The water has fallen below surface level, but is raised to an elevation of 20 feet by a small centrifugal pump and 6-horsepower gasoline engine.

No. 21.—Clarke's No. 4, NW. ¼ SE. ¼ sec. 31, T. 13, R. 20. A weir measurement on April 10, 1901, gave a discharge of 0.197 second-foot.

No. 22.—Alwardt, SE. ¼ SW. ¼ sec. 9, T. 12, R. 20. Weir measurement, March 21, 1890, gave a discharge of 0.64 second-foot.

No. 23.—Talent, H. H., NW. ¼ SW. ¼ sec. 5, T. 12, R. 20. Measurement made March 26, 1891, gave a discharge of 0.35 second-foot.

No. 24.—Clarke's No. 5, NE. ¼ sec. 31, T. 13, R. 20. No flow. Abandoned. Lost drill.

No. 25.—Conrad, sec. 5, T. 12, R. 20. Commenced December 20, 1900. In progress. Depth, 347 feet, March, 1891.

No. 26.—Longevin, sec. 8, T. 12, R. 20. Weir measurement, April 10, 1901, showed a discharge of 0.807 second-foot.

No. 27.—Buwalda No. 2, NW. ¼ NW. ¼ sec. 5, T, 12, R. 20. Measurement, April 10, 1901, with Price current meter, gave an approximate discharge of 0.566 second-foot.

No. 28.—Peck, J. W., NW. ¼ NE. ¼ sec. 6, T. 12, R. 20. Measurement with current meter on April 11, 1901, gave an approximate discharge of 1.10 second-feet.

No. 29.—Ryan, Robert, SW. ¼ SW. ¼ sec. 10, T. 12, R. 20. A weir measurement on March 21, 1891, gave a discharge of 0.485 second-foot.

No. 30.—Patterson, NW. ¼ SW. ¼ sec. 8, T. 12, R. 20. Commenced January 12, 1901. In progress. Depth, 640 feet March 21, 1901.

No. 31.—Gano, NE. ¼ SW. ¼ sec. 30, T. 13, R. 20. Measurement, March 29, 1891, gave a discharge of 632 second-feet.

No. 32.—Ellens, SE. ¼ NE. ¼ sec. 8, T. 12, R. 20. Depth, 676 feet. Some water. Well abandoned.

No. 33.—Hill, SW. ¼ SW. ¼ sec. 4, T. 12, R. 20. A trifling flow.

Wide Hollow.—Wilson, SW. ¼ SE. ¼ sec. 29, T. 13, R. 18. Discharge estimated at 0.75 second-foot. Well closed during winter of 1900–1901. Still closed.

Mabton.—Terrill and Hoover, SE. ¼ SE. ¼ sec. 7, T. 8, R. 23. Abandoned.

Sunnyside.—Turner, NE. ¼ NW. ¼ sec. 8, T. 10, R. 23. Abandoned.

Selah Valley.—Parker, sec. 23, T. 14, R. 20. Work temporarily discontinued.

Wenas Valley.—Arlington and Stoffer. Abandoned.

Warm Springs (10 miles east of Ellensburg).—John P. Clerf. Work in progress.

PALOUSE RIVER.

Estimated monthly discharge of Palouse River near Hooper, Wash.

[Drainage area, 2,210 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,770	320	1,082	66,530	0.490	0.565
February	4,892	166	1,526	84,750	.690	.719
March	4,859	735	2,097	128,939	.949	1.094
April	1,328	446	861	51,233	.390	.435
May	410	166	248	15,249	.112	.129
June	484	100	176	10,473	.080	.089
July	131	16	73	4,489	.033	.038
August	16	2	9	553	.004	.005
September	10	2	7	417	.003	.003
October	10	7	8	492	.004	.005
November	86	10	23	1,369	.010	.011
December	347	19	74	4,550	.033	.038
The year	4,892	2	515	369,044	.233	3.131

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 137; rating table on page 177 of same paper.

UMATILLA RIVER.

Estimated monthly discharge of Umatilla River at Gibbon, Oreg.

[Drainage area, 353 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,735	334	811	49,866	2.30	2.65
February	4,155	264	1,201	66,700	3.40	3.54
March	3,556	1,114	1,655	101,762	4.69	5.41
April	2,017	1,081	1,472	87,590	4.17	4.65
May	1,884	544	1,266	77,843	3.59	4.14
June	498	249	350	20,826	.99	1.10
July	233	124	181	11,129	.51	.59
August	124	88	98	6,026	.28	.32
September	159	88	125	7,438	.35	.39
October	188	159	166	10,207	.47	.54
November	203	172	181	10,771	.51	.57
December	617	203	398	24,472	1.13	1.30
The year	4,155	88	659	474,630	1.87	25.20

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 137; rating table on page 177 of same paper.

NORTHERN PACIFIC COAST DRAINAGE.

The measurement of four streams in that part of the State of Washington located between Puget Sound and the Pacific Ocean and known as the Olympic Peninsula has been continued during the year. The streams measured are Dungeness, Elwha, Kalawa, and Soleduck rivers, all of which head in the Olympic Mountains, the first two flowing northwardly into the Strait of San Juan de Fuca, and the last two flowing westwardly into the Pacific Ocean. The work of stream gaging at these stations was brought to a close at the end of 1901, several years' records having been obtained which give a fair indication of the regimen of these streams, and for the further reason that owing to the turbulent character of the streams much difficulty has been experienced in making accurate measurements.

The station on White River, at Buckley, Wash., was also maintained during 1901. This stream rises in central Washington and flows into Admiralty Sound.

ELWHA RIVER.

Estimated monthly discharge of Elwha River at McDonald, Wash.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,440	985	1,935	118,978	10.29	11.86
February	11,212	645	1,807	100,354	9.61	10.01
March	7,000	685	1,561	95,982	8.30	9.57
April	1,300	625	957	56,944	5.09	5.68
May	8,053	1,071	2,445	150,337	13.00	14.99
June	5,947	1,226	2,380	141,620	12.66	14.13
July	2,100	1,340	1,641	100,901	8.73	10.06
August	1,420	873	1,173	72,125	6.24	7.20
September	929	605	690	41,059	3.67	4.10
October	1,900	460	664	40,838	3.53	4.07
November	23,848	795	4,036	240,159	21.47	23.95
December	7,468	1,071	2,306	141,790	12.26	14.14
The year	23,848	460	1,800	1,301,087	9.57	129.76

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 139; rating table on page 177 of same paper.

KALAWA RIVER.

Estimated monthly discharge of Kalawa River near Forks, Wash.

[Drainage area, 213 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,710	314	1,723	105,943	8.09	9.33
February	5,212	300	1,151	65,034	5.40	5.62
March	5,212	620	1,372	84,361	6.44	7.42
April	2,438	566	997	59,325	4.68	5.22
May	5,022	314	949	58,352	4.46	5.14
June	909	314	478	28,443	2.24	2.50
July	300	147	180	11,067	.84	.97
August	158	0	48	2,951	.23	.27
September	170	0	41	2,440	.19	.21
October	2,704	0	199	12,236	.93	1.07
November	8,708	762	2,449	145,726	11.50	12.83
December	6,542	566	2,086	128,263	9.79	11.29
The year	11,710	0	973	704,141	4.57	61.87

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 140; rating table on page 177 of same paper.

SOLEDUCK RIVER.

Estimated monthly discharge of Soleduck River near Quillayute, Wash.

[Drainage area, 272 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	11,365	1,180	3,089	189,935	11.36	13.10
February	8,125	730	2,071	115,017	7.61	7.92
March	8,665	1,060	2,116	130,108	7.78	8.97
April	4,075	1,263	2,146	125,911	7.89	8.80
May	4,750	986	1,810	111,293	6.65	7.67
June	2,185	861	1,262	75,094	4.64	5.27
July	833	530	671	41,258	2.47	2.85
August	506	276	374	23,006	1.38	1.59
September	276	201	236	14,043	.87	.97
October	3,535	155	368	22,527	1.35	1.56
November	12,715	1,915	4,286	255,035	15.76	17.59
December	8,800	1,180	3,587	220,556	13.19	15.21
The year	12,715	155	1,835	1,323,783	6.75	91.50

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 141; rating table on page 177 of same paper.

SAN FRANCISCO BAY DRAINAGE.

Sacramento River, rising in northern California and flowing south, and the San Joaquin, rising in the southern sierras and flowing northeast, drain the western slope of the Sierra Nevada, traverse what is often called the Valley of California, and meet near Suisun Bay, finally discharging their waters into the Pacific Ocean through San Francisco Bay. Systematic measurements of discharge were made during 1901 of Sacramento River at Jellys Ferry, and of two of its tributaries, Stony Creek at Julian's ranch, near Fruto, and Cache Creek near the town of Lower Lake.

Stations were maintained during 1901 in the San Joaquin River drainage as follows: On Mokelumne River at Electra, on Stanislaus River near Oakdale, on Tuolumne River at Lagrange and at several points on its headwaters, on Merced River above Merced Falls, on San Joaquin River at Herndon, on King River near Red Mountain and near Kingsburg. Stations were maintained also on Tule River near Portersville and on Kern River at first point of measurement, near Bakersfield, both these streams belonging strictly to the above drainage.

SACRAMENTO RIVER.

Estimated monthly discharge of Sacramento River at Jellys Ferry, Cal.

[Drainage area, 9,134 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	74,240	8,915	20,983	1,290,194	2.30	2.66
February	101,880	9,800	34,138	1,895,928	3.74	3.89
March	46,100	12,200	20,628	1,268,366	2.26	2.61
April	16,700	9,200	10,870	646,810	1.19	1.33
May	13,700	7,530	9,804	602,824	1.07	1.23
June	7,265	4,965	5,596	332,985	.61	.68
July	4,760	3,980	4,365	268,393	.48	.55
August	3,980	3,805	3,850	236,727	.42	.48
September	5,380	3,630	3,922	233,375	.43	.48
October	5,380	3,980	4,194	257,879	.46	.53
November	44,100	4,360	7,745	460,859	.85	.94
December	61,800	5,380	12,149	747,013	1.33	1.53
The year	101,880	3,630	11,520	8,241,353	1.26	16.91

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 143; rating table on page 177 of same paper.

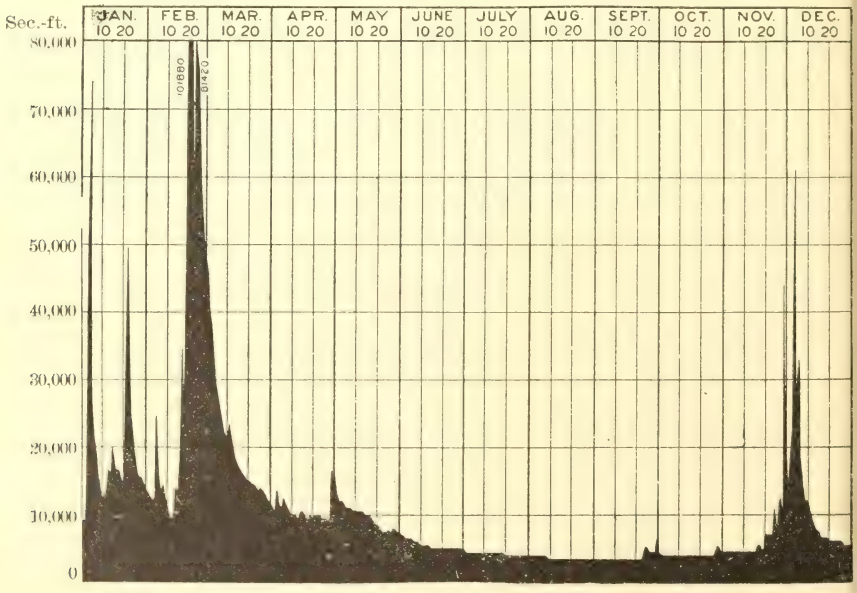

FIG. 64.—Discharge of Sacramento River at Jellys Ferry, Cal., 1901.

Estimated monthly discharge of Stony Creek near Fruto, Cal.

[Drainage area, 760 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	-------	-------	-------	-------	-------	-------
February	10,385	725	2,707	150,339	3.56	3.71
March	2,215	435	893	54,908	1.18	1.36
April	630	225	361	21,481	.48	.54
May	555	225	349	21,459	.46	.53
June	195	5	66	3,927	.09	.10
July	15	0	7	430	.01	.01
August	10	2	4	246	.01	.01
September	725	5	85	2,083	.05	.06
October	340	0	130	7,993	.17	.20
November	1,125	35	161	9,580	.21	.23
December	3,875	77	425	26,132	.56	.64
The year	10,385	0	428	298,578	.57	7.39

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 143; rating table on page 178 of same paper.

Estimated monthly discharge of Cache Creek near Lower Lake, California.

[Drainage area, 500 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,020	155	535	32,896	1.07	1.23
February	2,520	615	909	50,483	1.82	1.89
March	1,330	805	1,079	66,345	2.16	2.49
April	805	530	654	38,916	1.31	1.46
May	570	380	481	29,576	.96	1.10
June	415	255	327	19,458	.65	.72
July	255	155	199	12,236	.40	.46
August	155	86	114	7,010	.23	.26
September	86	40	55	3,273	.11	.12
October	50	16	31	1,906	.06	.07
November	62	16	26	1,547	.05	.06
December	74	40	62	3,812	.12	.14
The year	2,520	16	373	267,458	.75	10.00

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 144; rating table on page 178 of same paper.

MOKELUMNE RIVER.

Estimated monthly discharge of Mokelumne River at Electra, Cal.

[Drainage area, 537 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	4,600	330	1,000	61,488	1.86	2.14
February	13,210	610	3,302	183,384	6.15	6.42
March	4,020	1,130	2,004	123,221	3.73	4.30
April	3,160	950	2,040	121,388	3.80	4.24
May	9,980	1,960	4,627	284,503	8.62	9.93
June	6,790	1,350	3,833	228,145	7.14	7.97
July			[a] 260	[a] 15,987	[a] .49	[a] .56
August			[a] 190	[a] 11,683	[a] .36	[a] .42
September			[a] 60	[a] 3,570	[a] .11	[a] .12
October			[a] 76	[a] 4,673	[a] .14	[a] .16
November			[a] 210	[a] 12,496	[a] .39	[a] .44
December			[a] 1,467	[a] 45,467	[a] 2.73	[a] 3.15
The year			[a] 1,589	[a] 1,096,005	[a] 2.96	[a] 39.85

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 145; rating table on page 178 of same paper.

SAN JOAQUIN RIVER.

Estimated monthly discharge of Tuolumne River at Hetch Hetchy Valley dam site, California.

[Drainage area, 400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	7,620	1,550	3,476	206,836	8.69	9.70
July	3,650	1,200	2,159	132,752	5.40	6.21
August	1,122	127	427	26,255	1.07	1.23
September	147	86	109	6,486	.27	.30

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 147.

Estimated monthly discharge of Eleanor Creek at Eleanor Trail Crossing, California.

[Drainage area, 81 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	1,834	374	824	49,031	10.10	11.35
July	510	138	275	16,909	3.40	3.92
August	122	18	52	3,197	.64	.74
September	18	5	8	476	.01	.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 147.

Estimated monthly discharge of Cherry River at Eleanor Trail Crossing, California.

[Drainage area, 130 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
June	[a] 1,950	750	1,202	71,525	9.25	10.32
July	1,630	218	653	40,145	5.02	5.78
August	206	17	93	5,718	.72	.83
September	145	4	32	1,904	.25	.28

[a] Approximate.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 148.

Estimated monthly discharge of Tuolumne River at Lagrange, Cal.

[Drainage area, 1,501 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	18,280	560	3,351	206,145	2.23	2.58
February	19,240	1,440	7,203	400,090	4.80	5.00
March	7,080	2,080	3,719	228,733	2.48	2.86
April	7,080	1,740	3,960	235,696	2.64	2.94
May	13,160	4,075	8,035	494,114	5.36	6.18
June	13,160	4,900	9,387	558,566	6.26	6.98
July	9,960	1,440	3,700	227,566	2.47	2.85
August	2,080	200	784	48,206	.52	.60
September	350	55	175	10,413	.12	.13
October	1,590	0	211	12,974	.14	.16
November	1,300	300	574	34,155	.38	.43
December	5,800	200	1,339	82,332	.89	1.02
The year	19,240	0	3,537	2,538,990	2.36	31.73

Mining Company's canal flows 10 second-feet continuously from January 1 to March 31, 1901, and 7 second-feet continuously from April 1 to July 28, 1901.

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 149; rating table on page 178 of same paper.

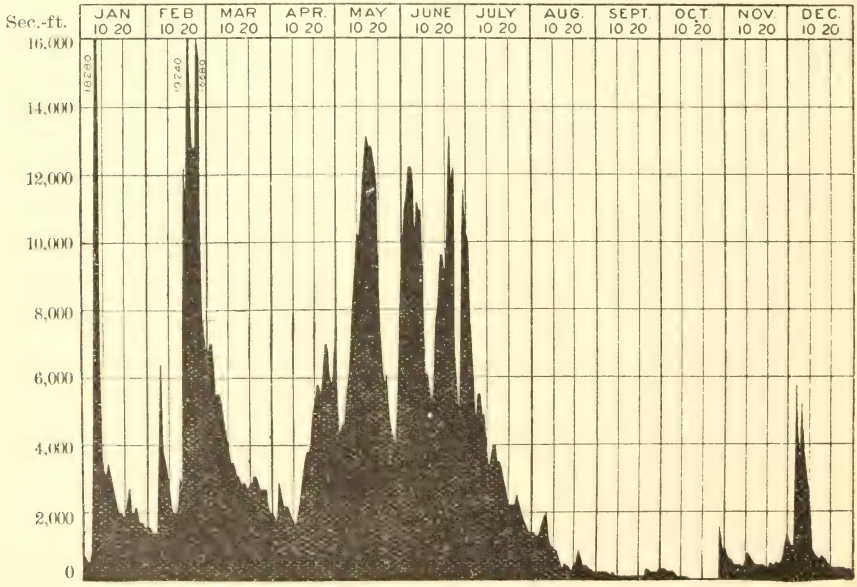

FIG. 65.—Discharge of Tuolumne River at Lagrange, Cal., 1901.

Estimated monthly discharge of Merced River above Merced Falls, Cal.

[Drainage area, 1,090 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	5,000	1,090	2,687	133,240	1.55	1.44
May	9,450	2,700	5,419	333,201	4.97	5.73
June	8,220	3,380	5,390	320,678	4.94	5.50
July	4,560	1,090	2,096	128,878	1.92	2.21
August	2,090	220	704	43,287	.65	.75
September	250	130	183	10,889	.17	.19
October	990	150	265	16,294	.24	.28
November	730	0	399	23,742	.37	.41
December	2,090	220	577	35,478	.53	.61

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 150; rating table on page 178 of same paper.

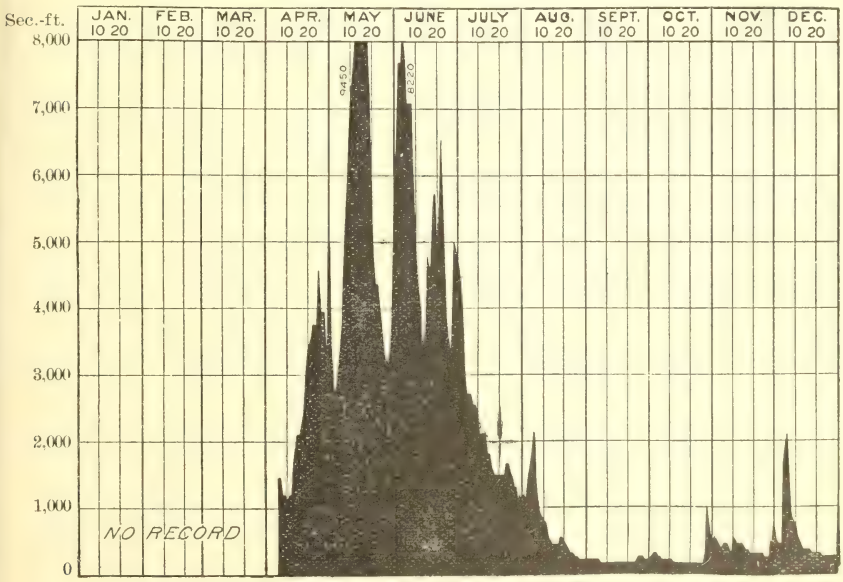

FIG. 66.—Discharge of Merced River above Merced Falls, Cal., 1901.

Estimated monthly discharge of San Joaquin River at Herndon, Cal.

[Drainage area, 1,637 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	21,372	810	3,506	215,576	2.14	2.47
February	12,940	1,550	4,983	276,742	3.04	3.17
March	6,830	2,480	4,191	257,695	2.56	2.95
April	12,400	1,930	4,680	278,479	2.86	3.18
May	17,870	4,775	10,935	672,367	6.68	7.71
June	15,662	7,882	11,998	713,930	7.33	8.17
July	14,294	3,110	3,466	213,116	2.12	2.45
August	5,850	500	2,373	145,910	1.45	1.67
September	500	360	399	23,742	.24	.27
October	2,480	340	489	30,067	.30	.35
November	1,550	500	702	41,772	.43	.48
December	2,060	460	872	53,617	.53	.61
The year	21,372	340	4,050	2,923,013	2.47	33.48

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 151; rating table on page 178 of same paper.

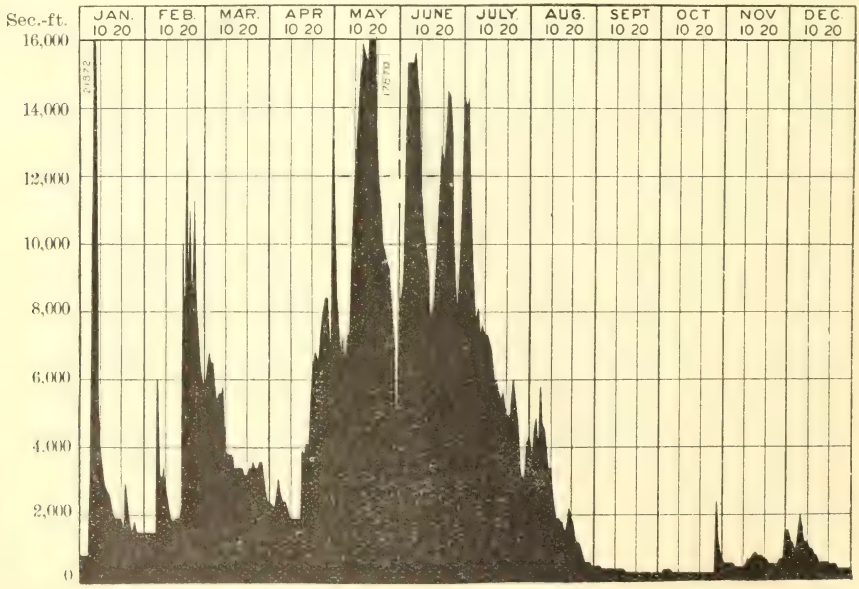

FIG. 67.—Discharge of San Joaquin River at Herndon, Cal., 1901.

Estimated monthly discharge of King River near Red Mountain, California.

[Drainage area, 1,742 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	43,930	520	4,337	266,672	2.49	2.87
February	7,040	1,040	3,318	190,392	1.90	2.00
March	4,490	2,034	2,965	182,311	1.70	1.96
April	10,840	1,642	4,492	267,293	2.58	2.87
May	21,830	5,548	11,093	682,082	6.37	7.36
June	21,180	7,040	14,363	854,658	8.25	9.20
July	13,240	3,280	6,258	384,789	3.59	4.14
August	6,260	728	2,292	140,930	1.32	1.52
September	780	440	534	31,775	.31	.35
October	2,034	360	535	32,896	.31	.36
November	1,450	480	694	41,296	.40	.45
December	1,170	440	667	41,073	.38	.44
The year	43,930	360	4,296	3,116,167	2.47	33.52

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 152; rating table on page 178 of same paper.

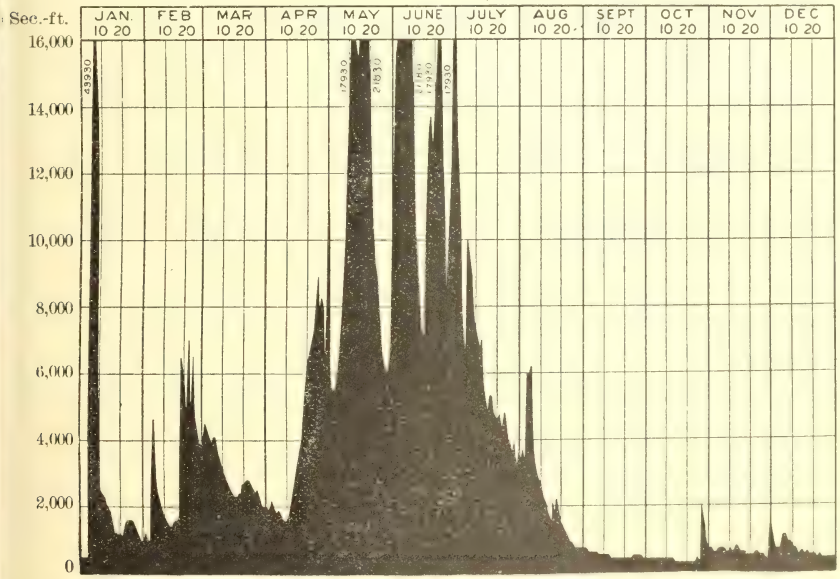

FIG. 68.—Discharge of King River near Red Mountain, California, 1901.

TULE RIVER.

Estimated monthly discharge of Tule River near Portersville, Cal.

[Drainage area, 437 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	875	298	418	25,702	0.96	1.10
June	408	126	240	14,281	.55	.61
July	126	30	61	3,751	.14	.16
August	30	18	19	1,168	.04	.04
September	23	10	17	1,012	.04	.04
October	109	18	29	1,783	.07	.08
November	71	35	43	2,559	.10	.11
December	64	39	50	3,074	.11	.13

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 157; rating table on page 178 of same paper.

KERN RIVER.

Estimated monthly discharge of Kern River near Bakersfield, Cal.

[Drainage area, 2,345 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,049	226	493	30,313	0.21	0.24
February	1,963	342	860	47,762	.37	.39
March	1,658	901	1,270	78,089	.54	.62
April	2,632	637	1,398	83,187	.60	.67
May	4,295	2,091	3,032	186,430	1.29	1.49
June	4,212	2,455	3,324	197,792	1.42	1.58
July	3,856	1,120	1,864	114,613	.80	.92
August	1,804	505	968	59,520	.41	.47
September	526	249	345	20,529	.15	.17
October	756	259	317	19,492	.14	.16
November	421	343	377	22,433	.16	.18
December	457	268	323	19,860	.14	.16
The year	4,295	226	1,216	880,020	.52	7.05

NOTE.—Daily discharge for 1901 is given in Water-Supply Paper No. 66, page 159.

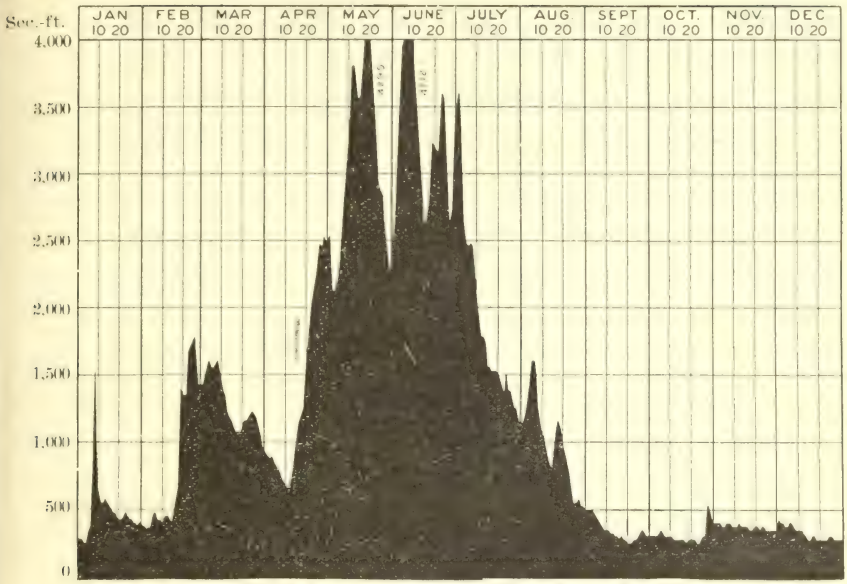

FIG. 69.—Discharge of Kern River near Bakersfield, Cal., 1901.

SOUTHERN CALIFORNIA DRAINAGE.

Under this head have been grouped all of the streams of southern California which do not drain directly or indirectly into San Francisco Bay. The measurements made on Salinas River and tributaries were brought to a close during 1901, the object for which the stations had been established, that is, furnishing the necessary data for computing the water supply available for the reservoir sites surveyed in the Salinas basin, having been accomplished. Measurements were continued on Mohave River at Victorville, on Santa Ana River below Warmsprings, and on San Gabriel River near Azusa. Records were also obtained of the flow of Lytle Creek, and of Mill Creek at Crafton headworks. Results for 1901 are given in the following pages.

SALINAS RIVER.

Estimated monthly discharge of Nacimiento Creek near Bryson, Cal.

[Drainage area, 171 square miles.]

Month.	Discharge in second-feet.				Run-off.	
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Second-feet per square mile.	Depth in inches.
1901.						
March	365	110	184	11,314	1.08	1.25
April	670	87	99	5,891	.58	.64

NOTE. Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 154.

Estimated monthly discharge of San Antonio Creek near Jolon, Cal.

[Drainage area, 161 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	3,700	64	523	32,158	3.25	3.75
February	1,700	110	509	28,268	3.17	3.30
March	400	84	171	10,514	1.06	1.22
April	740	39	83	4,939	.52	.58

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 154; rating table on page 178 of same paper.

Estimated monthly discharge of San Lorenzo Creek near King City, Cal.

[Drainage area, 235 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	2,540	9	171	10,514	0.73	0.84
February	9,200	9	725	40,264	3.09	3.21
March	27	9	17	1,045	.07	.08
April	27	6	8	476	.03	.03

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 155; rating table on page 178 of same paper.

Estimated monthly discharge of Arroyo Seco near Piney, Cal.

[Drainage area, 215 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	4,500	105	888	54,601	4.13	4.77
February	2,860	160	931	51,705	4.33	4.51
March	610	105	246	15,126	1.14	1.31
April	2,500	95	195	11,603	.91	.91

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 156; rating table on page 178 of same paper.

Estimated monthly discharge of Salinas River near Salinas, Cal.

[Drainage area, 4,084 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	35,162	380	4,921	302,580	1.20	1.38
February	20,927	540	4,131	231,701	1.01	1.05
March	1,772	430	1,063	65,361	.26	.30
April	405	160	270	16,066	.07	.08
May	2,012	160	533	32,773	.13	.15
June	160	30	56	3,332	.01	.01
July	30	25	27	1,660	.01	.01

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 156; rating table on page 178 of same paper.

MOHAVE RIVER.

Estimated monthly discharge of Mohave River at Victorville, Cal.

[Drainage area, 400 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	44	44	44	2,705	0.11	0.13
February	60	44	49	2,721	.12	.12
March	80	44	57	3,505	.14	.16
April	44	33	35	2,083	.09	.10
May	33	33	33	2,029	.08	.09
June	33	25	30	1,785	.08	.09
July	29	25	26	1,599	.06	.07
August	29	29	29	1,783	.07	.08
September	29	29	29	1,726	.07	.08
October	33	29	32	1,968	.08	.09
November	3,200	33	139	8,271	.35	.39
December	33	33	33	2,029	.08	.09
The year	3,200	25	45	32,204	.11	1.49
1901.						
January	4,180	50	183	11,252	.46	.53
February	4,820	50	925	51,372	2.31	2.41
March	660	50	178	10,945	.45	.52

Estimated monthly discharge of Mohave River at Victorville, Cal.—Continued.

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
April	44	44	44	2,618	.11	.12
May	49	49	49	3,013	.12	.14
June	42	42	42	2,499	.11	.12
July	40	40	40	2,460	.10	.12
August	50	50	50	3,074	.13	.15
September	55	55	55	3,273	.14	.16
October	69	69	69	4,243	.17	.20
November	77	77	77	4,582	.19	.21
December	73	73	73	4,489	.18	.21
The year	4,820	40	149	103,820	.37	4.89

NOTE.—Gage heights and discharge measurements for 1901 are given in Water-Supply Paper No. 66, page 160.

SAN GABRIEL RIVER.

Estimated monthly discharge of San Gabriel River and canals above Azusa, Cal.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1900.						
January	89	22	32	1,968	0.14	0.16
February	23	18	20	1,111	.09	.09
March	30	16	20	1,230	.09	.10
April	26	13	17	1,012	.08	.09
May	86	16	37	2,275	.17	.20
June	22	8	15	893	.07	.08
July	10	4	6	369	.03	.03
August	5	4	4	246	.02	.02
September	6	3	4	238	.02	.02
October	6	4	5	307	.02	.02
November			[a] 186	11,068	.84	.93
December			[a] 40	1,269	.18	.11
The year			[a] 32	21,986	.15	1.85

[a] Approximate.

IRRIGATING A FIELD OF SUGAR BEETS IN PECOS VALLEY, NEW MEXICO.

Estimated monthly discharge of San Gabriel River and canals near Azusa, Cal.

[Drainage area, 222 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	1,450	28	169	10,391	0.76	0.87
February	2,605	137	680	37,765	3.06	3.19
March	440	135	221	13,589	1.00	1.15
April	130	95	110	6,545	.50	.56
May	272	83	121	7,440	.55	.63
June	93	41	63	3,749	.28	.31
July	41	24	30	1,845	.14	.16
August	27	15	20	1,240	.09	.10
September	20	15	17	1,012	.08	.09
October	122	0	24	1,476	.11	.13
November	50	29	32	1,904	.14	.16
December	30	26	27	1,660	.12	.14
The year	2,605	0	126	88,606	.57	7.49

NOTE.—Gage heights of San Gabriel River for 1901 are given in Water-Supply Paper No. 66, page 161; daily discharge of canals on page 162 of same paper.

LYTLE CREEK.

Estimated monthly discharge of Lytle Creek at head gates Rialto canals, California.

[Drainage area, 52 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
May	21.7	12.1	15.8	971	0.30	0.35
June	15.2	10.5	12.6	750	.24	.27
July 1–23	.....	.....	10.0	456	.19	.16
August	11.3	9.7	10.4	639	.20	.23
September	11.5	8.7	9.8	583	.19	.21
October 1–25 and 29–31	.....	.....	12.7	705	.24	.25

SANTA ANA RIVER.

Estimated monthly discharge of Santa Ana River and canals near Warmsprings, Cal.

[Drainage area, 188 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
January	600	31	78	4,796	0.41	0.47
February	540	48	194	10,774	1.03	1.07
March	114	45	68	4,181	.36	.41
April	107	39	43	2,559	.23	.26
May	68	35	42	2,582	.22	.25
June	44	30	37	2,202	.20	.22
July	42	34	38	2,337	.20	.23
August	200	31	50	3,074	.27	.31
September	60	42	49	2,916	.26	.29
October	96	24	48	2,951	.26	.30
November	36	22	26	1,547	.14	.16
December	25	21	24	1,476	.13	.15
The year	600	21	58	41,395	.31	4.12

NOTE.—Daily discharge of river and canals for 1901 is given in Water-Supply Paper No. 66, pages 164-165.

MILL CREEK.

Estimated monthly discharge of Mill Creek canals at Crafton head works, California.

[Drainage area, 47 square miles.]

Month.	Discharge in second-feet.			Total in acre-feet.	Run-off.	
	Maximum.	Minimum.	Mean.		Second-feet per square mile.	Depth in inches.
1901.						
July	19.12	13.94	15.86	975	0.34	0.39
August	.....	.....	[a] 19.07	867	.41	[a] .35
September	16.58	11.42	14.04	833	.30	.33
October	13.18	12.30	12.58	774	.27	.31
November	12.30	11.60	12.28	732	.26	.29
December	12.28	10.26	12.00	738	.26	.30

[a] Partial month.

NOTE.—Daily discharge in second-feet for 1901 is given in Water-Supply Paper No. 66, page 166.

RELATION OF RAINFALL TO RUN-OFF IN CALIFORNIA.

A study of the available rainfall and run-off data for California watersheds has been undertaken, and the accompanying diagrams and tables are here presented as the results of the work.

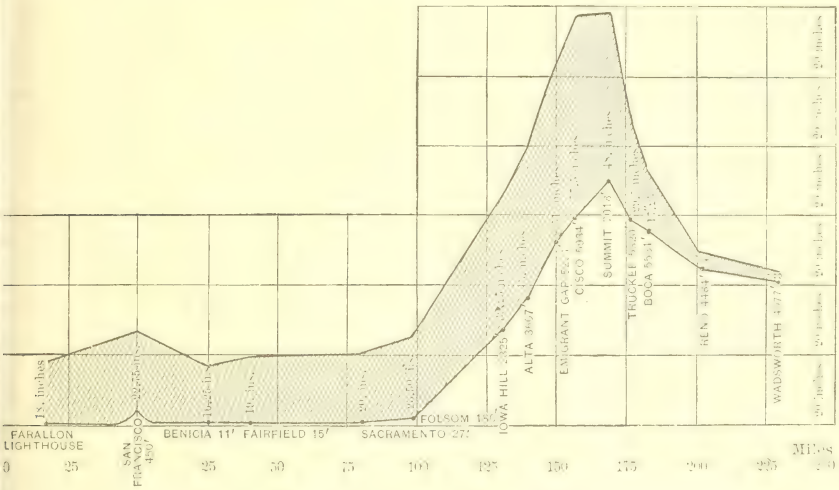

FIG. 70.—Diagram showing increase of rainfall with rise of elevation over the Sierras in central California.

As the run-off diagram was to be used in estimating the water supply available for various storage reservoirs for irrigation, it was thought best to represent the run-off in acre-feet per square mile. The majority of the discharge reports give the depth of run-off in inches. The accompanying table has been made for converting depth of run-off in inches to run-off in acre-feet per square mile, using the following formula: Depth of run-off in inches, x (0.0833 x 640) = run-off in acre-feet per square mile.

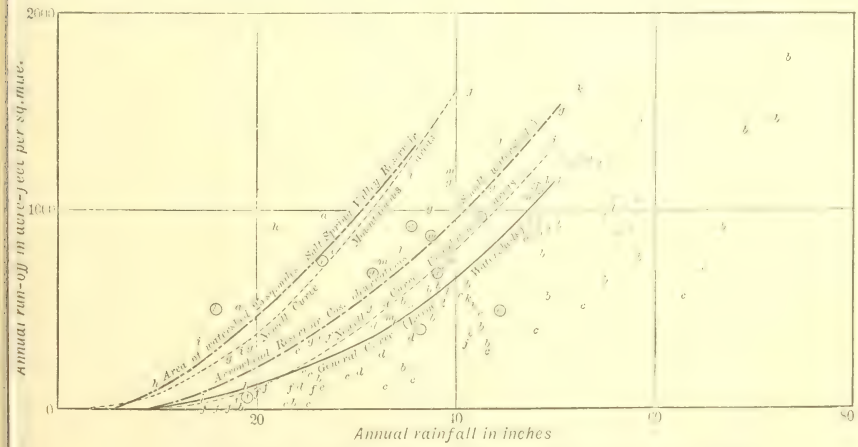

FIG. 71.—Diagram showing run off from watersheds of California streams.

Table for converting depth of run-off in inches into acre-feet per square mile.

Depth of run-off.	Acre-feet per square mile.	Depth of run-off.	Acre-feet per square mile.	Depth of run-off.	Acre-feet per square mile.
Inches.		*Inches.*		*Inches.*	
0.01	0.533	0.35	18.667	0.69	36.800
.02	1.067	.36	19.200	.70	37.333
.03	1.600	.37	19.733	.71	37.867
.04	2.133	.38	20.267	.72	38.400
.05	2.667	.39	20.800	.73	38.933
.06	3.200	.40	21.333	.74	39.467
.07	3.733	.41	21.867	.75	40.000
.08	4.267	.42	22.400	.76	40.533
.09	4.800	.43	22.933	.77	41.067
.10	5.333	.44	23.467	.78	41.600
.11	5.867	.45	24.000	.79	42.133
.12	6.400	.46	24.533	.80	42.667
.13	6.933	.47	25.067	.81	43.200
.14	7.467	.48	25.600	.82	43.733
.15	8.000	.49	26.133	.83	44.267
.16	8.533	.50	26.667	.84	44.800
.17	9.067	.51	27.200	.85	45.333
.18	9.600	.52	27.733	.86	45.867
.19	10.133	.53	28.267	.87	46.400
.20	10.667	.54	28.800	.88	46.933
.21	11.200	.55	29.333	.89	47.467
.22	11.733	.56	29.867	.90	48.000
.23	12.267	.57	30.400	.91	48.533
.24	12.800	.58	30.933	.92	49.067
.25	13.333	.59	31.467	.93	49.600
.26	13.867	.60	32.000	.94	50.133
.27	14.400	.61	32.533	.95	50.667
.28	14.933	.62	33.067	.95	51.200
.29	15.467	.63	33.600	.97	51.733
.30	16.000	.64	34.133	.98	52.267
.31	16.533	.65	34.667	.99	52.800
.32	17.067	.66	35.200	1.00	53.333
.33	17.600	.67	35.733		
.34	18.133	.68	36.267		

At the outset many difficulties began to present themselves. The most serious one was that of obtaining measurements of rainfall at the higher elevations. The streams most productive of run-off, and upon which discharge records had been kept, have their sources on the western slopes of the high Sierra Nevada Mountains, where there

are few or no inhabitants above 7,000 feet, and consequently no observers of rainfall, but the valuable rainfall records of the Pacific Railway system along the line of railway from Sacramento to the summit of the Sierra Nevada at Railroad Pass offered a clew to the solution of this difficulty. In fig. 70 the mean rainfall and the elevation of the station are plotted as ordinates and the distance inland of the station as abscissas.

The rate of increase of precipitation from Sacramento to Cisco, at the elevation of 6,000 feet, the point of maximum rainfall, seems to be 0.6 inch per 100 feet of rise. The precipitation above the 6,000-foot point decreases with the elevation approximately at the rate of 0.4 inch per 100 feet of rise.

Fortunately in the Tuolumne River Basin, about midway between the American and King River basins, there is another series of rainfall stations, beginning with Lagrange, elevation 293 feet above sea level; Sonora, elevation 1,824 feet; Second Garrote, elevation 2,900 feet, and Crockers, elevation 4,453 feet. The mean rainfall at these stations, plotted as in the above diagram, indicates the rate of increase from Lagrange to Crockers to be 0.84 inch per 100 feet rise. This rate of increase has been taken to hold good up to an elevation of 6,000 feet, and above this the rate of decrease of rise to be 0.4 inch per 100 feet to an elevation of 9,000 feet. Probably the rate of increase and decrease would be more correctly represented by a curved line, but the data are not sufficient to warrant this.

Using these rates of increase and decrease, the mean precipitation for the years 1896–1899 at an elevation of 9,000 feet in the Tuolumne River Basin would be 49.8 inches. If snow converts into water at the ratio of 8 to 1, the snowfall would be 33.2 feet at this elevation.

It was found impossible to use the run-off data of the Kern River Basin, though it is without doubt the most closely watched stream in the State, because of the exposure of the watershed and because of the scarcity of rainfall data. This watershed is bounded on the west for almost its entire length by a high mountain range. Concerning the precipitation on the east slope of this range there is little known beyond the fact that it is very much less than on the western slope.

In 1896 the total run-off from the King River Basin of 1,775 square miles was 1,871,005 acre-feet. For the same year the run-off from the Kern River Basin was 619,630 acre-feet. The ratio of the area of the King River Basin to the Kern is 1 to 1.32, the ratio of run-off 1 to 0.33, though the higher drainage areas of the streams are contiguous. It was also thought best not to use the run-off and rainfall data for Piru Creek Basin, furnished by the Antelope Valley Water Company, because the ratio of discharge in acre-feet per square mile was greater than any other record. There is little doubt about the accuracy of both the run-off and precipitation records, the explanation being that the rainfall observation stations were necessarily situated at so low an

elevation that the record did not represent the mean rainfall for the higher portions of the basin.

The run-off and rainfall data of the streams which were used to make the discharge diagram, fig. 71, will be mentioned in the order from north to south in which their watersheds occur.

Sacramento River Basin.—The rainfall stations used in determining the mean annual precipitation for the Sacramento River Basin were the following: Red Bluff, Rosewood, Redding, Delta, Dunsmuir, Shasta, Sissons, and Fort Bidwell.

There were absolutely no records for the great interior mountainous and lava country in Siskiyou, Modoc, and Lassen counties, comprising more than 5,334 square miles of the watershed.

Fort Bidwell is situated outside of the watershed, on the eastern slope of the mountains that form the boundary, and would probably have a less rainfall than Modoc County. The record was kept there for a period of twenty-two years, and the mean rainfall is 20.8 inches.

The average rainfall at Red Bluff for a period of twenty-three years was 23.9 inches; at Rosewood, for a period of six years, 25.63; at Redding, for twenty-four years, 35.69. The precipitation at these three latter stations was taken to get the average for the Sacramento Valley for the years 1896–1899, during which time run-off measurements have been made at Jellys Ferry. The mean rainfall of the Pitt River drainage area of 5,334 square miles, which has an average elevation of 5,000 feet, was taken to be the same as that of the Sacramento Basin above Red Bluff.

The average rainfall at Delta for a period of fourteen years was 62.39 inches; at Dunsmuir, for ten years, 57.16 inches; at Shasta, for six years, 53.26 inches; at Sissons, for ten years, 32.75 inches. The rainfall at these four stations was taken to obtain the mean rainfall for the mountainous area of the watershed for the years 1896–1899.

San Mateo Creek.—The Spring Valley Water Company's record of rainfall and run-off from the watershed of San Mateo Creek is without doubt the oldest record in the State, having been kept for thirty years. In the table given on page 390 of Water-Supply and Irrigation Paper No. 38, of the United States Geological Survey, no allowance has been made for evaporation from the surface of the reservoir; 20 per cent has here been added to the run-off as calculated from those tables to cover evaporation. The drainage basin of San Mateo Creek ranges in elevation from 250 to 1,800 feet, with an average of about 750 feet. The hills are undulating. There is a limited growth of timber on the northern slopes near the summit, but a large amount of brush covers other portions of the basin. On the southern slopes and crest the hills are frequently bare of brush, but covered with grasses.

Salt Springs Valley watershed.—The basin of the Salt Springs

Valley is largely of red clay, which scantily covers a bed rock of granite and slate. The topography is undulating rather than mountainous, about 20 per cent of the total drainage area being valley land. There is little brush or timber in the valley and only a scattering growth of oak and scrubby pine on the hills. To obtain the mean for the basin 10 per cent has been added to the rainfall for North Hill, 6 miles northwest of the dam. To obtain the total run-off for the basin 4,132 acre-feet have been added to the amounts as given in the table on page 337, Part IV, of the Eighteenth Annual Report of the United States Geological Survey to compensate for evaporation from the reservoir surface.

The methods of measurement of discharge from the reservoir are very crude, which may partly account for the very high percentage of run-off from this basin, which contains 25 square miles.

Stanislaus River Basin.—There were no rainfall data obtainable for this basin, but, since it joins the Tuolumne and is in most respects similar, the rainfall for the Tuolumne Basin has been taken to apply to both.

Tuolumne River Basin.—To obtain the mean rainfall for this basin the average elevation and area of the various portions were taken from the topographic maps of the United States Geological Survey. The areas were obtained by the use of a planimeter. Lagrange was taken as the base station and the percentage of increase for the various elevations, as shown by the diagram, fig. 1. The following example for the year 1896 will illustrate more particularly the method:

Average elevation.	Number of square miles.	Estimated rainfall, 1896.	Mile-inches.
1,200	75	26.4	1,980
1,500	88	29.0	2,552
2,500	182	37.4	6,807
3,500	46	45.8	2,107
4,000	105	50.0	5,252
4,500	147	54.2	7,967
5,500	90	60.9	5,481
6,000	143	63.3	9,052
6,500	105	61.3	6,437
7,500	189	57.3	10,830
9,000	330	51.3	16,927
	1,500		75,692

$\frac{75692}{1500} = 50.3$ inches mean for basin, 1896.

Tabulation of general curve.

Estimated mean rainfall in inches.	Estimated run-off in acre-feet per square mile.	Estimated depth of run-off in inches.	Estimated mean rainfall in inches.	Estimated run-off in acre-feet per square mile.	Estimated depth of run-off in inches.
8	0	.00	30	330	6.20
10	10	.19	32	380	7.13
12	15	.28	34	430	8.06
14	35	.66	36	500	9.38
16	55	1.03	38	580	10.87
18	85	1.60	40	660	12.38
20	120	2.25	42	750	14.06
22	160	3.00	44	840	15.75
24	200	3.75	46	940	17.62
26	240	4.50	48	1,040	19.50
28	280	5.25	50	1,160	21.75

San Joaquin and King River basins.—There were practically no rainfall data for either of these basins.

The estimated mean rainfall for the Tuolumne River Basin for the years 1896–1899 is 48.2 inches; the depth of mean run-off for the same period is 20.8 inches; the depth of mean run-off for the San Joaquin River for this period is 18.4 inches. Since the topography, exposure, etc., in the two basins are similar, the rainfall will probably be proportional to the run-off.

Example: 20.8 : 18.4 : : 48.2 : 42.7. Similarly the mean rainfall for the King River Basin will be 37.8 inches.

Mohave River.—The meteorological and hydrographic work of the Arrowhead Water Company has been carried on for a number of years at the head of the Mohave River. Twenty-eight rain gages, carefully located at elevations of from 2,100 to 7,200 feet, have been maintained. The measurements of run-off from several tributaries have been made over weirs. The area of the basins are all less than 50 square miles. The watershed is covered with a thick growth of timber on the crest. The growth of timber diminishes as the desert is approached, the northern part of the watershed being covered with brush only. The mean elevation of the watershed observed upon is about 5,250 feet above sea level.

Cuyamaca reservoir watershed.—The area of this watershed is 11 square miles and the mean elevation above sea level is probably 5,500 feet.

The run-off is carefully measured. There is only one rain gage maintained, and that is at the dam. The resident engineer, Mr. F. S. Hyde, says that as this rain gage is located between two high wooded

peaks, which act as condensers of the moisture-laden clouds, the recorded precipitation is undoubtedly heavier than the average of the watershed. This probably explains why the mean annual run-off is so far below the general curve.

Sweetwater reservoir basin.—The evaporation and run-off records from this basin date from 1888, and have been very carefully kept.

There is no doubt that many of the points on the curves (fig. 71), would be changed if we had more definite information as to the rainfall, but the curves are the best that could be made from the information at hand. The mean discharge for the period of observation on each stream is used, together with the mean rainfall for the same years. These means are considered the more satisfactory, as they tend to eliminate erratic stream and rainfall records.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

OBSERVATIONS ON THE FLOW OF RIVERS

IN THE

VICINITY OF NEW YORK CITY

BY

HENRY ALBERT PRESSEY

GOVERNMENT PUBLICATIONS
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1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., June 23, 1902.

SIR: I transmit herewith manuscript for Water-Supply and Irrigation Paper No. 76, by H. A. Pressey, entitled Observations on the Flow of Rivers in the Vicinity of New York City.

Respectfully,

F. H. NEWELL,
Hydrographer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

OBSERVATIONS ON THE FLOW OF RIVERS IN THE VICINITY OF NEW YORK CITY.

By H. A. Pressey.

INTRODUCTION.

One of the chief resources of the United States is its water supply. The prominent industrial position of several States is due largely to the abundance of their available water. It has recently been stated that "the preeminent position of the State of New York is due almost entirely to her great natural resources;" that "her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth," and that "the history of the State's progress during the nineteenth century is largely a history of the development of her water resources." These remarks apply quite as aptly to some of the New England States, as they could not have held the front rank in the industrial world for so many years were it not for the very extensive utilization of the magnificent waterfalls of that region. In the Southern Atlantic States the great developments during the last few years are due largely to the development and utilization of water powers.

There is not a State along the Atlantic coast, except Delaware, that does not contain water powers, developed and undeveloped, and, contrary to the opinion of many, there never was a decade in the history of our country when the development of water power made such strides as during the last ten years. According to the returns of the Twelfth United States Census the increase in the utilization of water power in the United States in the ten years from 1890 to 1900 was about 30 per cent, or 472,361 horsepower. In some States this increase was remarkable, as, for instance, in Maine, where in the last decade the developed power increased 60 per cent.

The importance of our water powers as a source of wealth can hardly be overestimated. This power is not confined, however, to the Eastern States, for in the great Central Northwest, on the Pacific slope, and elsewhere there are water powers of great size and value, many of which form the basis of the industrial life of large communities. In the broad, flat plains of the United States west of the Mississippi

the rivers are valuable from another standpoint. In this region the streams commonly lack the fall required for power development, but here the water supply is, perhaps, more vital to the life of the region than in the coastal States. Great areas of land depend for water largely upon the rivers in their vicinity and upon artificial means for raising and distributing it over their soils. Without water there can be no life in this region; with water, vast areas can be reclaimed as agricultural land of great fertility.

In most parts of the country the public water supply of the cities and towns must be derived from the rivers. Large sums are expended every year in conducting water from the streams to the centers of population. Before this money is expended it is of the greatest importance to know that there is sufficient water at all times for the use of the town. Too often have great hydraulic works been built before proper investigation has been made of the flow of a stream, and great financial loss has resulted.

It is to furnish information upon which to base estimates of available water supply that the Hydrographic Division of the United States Geological Survey has been, during the last fourteen years, collecting data in regard to the flow of rivers in the United States, and their variation from season to season and throughout a series of years. The necessity for such data is frequently brought to the attention of the engineer, sometimes in a most startling manner. The lack of this information frequently leads to the most disastrous mistakes in the construction of hydraulic works. One of the best examples of this in the design of a hydraulic plant was the construction of a dam and water-power plant at Austin, Tex. After an expenditure of $1,600,000 it was found that a grave mistake had been made in the estimate of the low-water flow. The works were constructed by the city in accordance with a vote of the citizens of Austin in 1890. It was estimated that 14,000 horsepower could be developed, and the people felt that their city was to become a great manufacturing center. No hydrographic data had been collected, except from the hazy memory of the "oldest inhabitant." In the spring of 1890 a measurement of flow giving 1,000 cubic feet per second was taken as the minimum. This estimate was more than five times too great, as was shown by subsequent measurements. An error of 500 per cent had been made in the estimate, but this was not ascertained until the works were nearly completed.

Mistakes of this kind have occurred in every part of the country in hydraulic works. The Sweetwater dam in California in a good example of a project carried through on insufficient data. The dam was built after a series of wet years and was soon after filled to overflowing, so that increased spillways were constructed, but since that time the water in the reservoir has never reached an elevation near the crest of the spillways, and during most of the time there has been the greatest scarcity of water.

The Bear Valley dam is a more marked case, as the reservoir formed by the dam has been practically dry for several years, so that wells have been driven in the bottom of it.

The Gila Bend, Arizona, project is another example of the expenditure of a large sum—$900,000—upon insufficient data, and subsequent abandonment of the scheme. In this project the dam was carried away before its completion, but had it been completed the scheme must have proved a financial failure.

Many diversion canal projects for irrigation have been either partial or complete failures on account of shortage of water; that is, developments have been made far beyond the capacity of the stream.

A great number of water-power plants have been constructed upon insufficient data, and later, auxiliary steam has been found necessary. Allowance was not made in the original estimates, so that in a number of instances the project has been found unprofitable. Knowl- of the flood flow is also of great importance in designing the dams and waste ways.

Frequently the cause of such errors is a complete ignorance of the hydrographic conditions in the drainage basin of the stream and often of the region in which the stream is located. In a few cases no adequate efforts have been made to obtain information; perhaps a single measurement may have been made at a time when a local resident informed the investigator that the "river is now as low as it ever gets." In order to test the accuracy of such methods, the writer has often asked old inhabitants on the banks of the river as to the variation in the river height, and has been informed that "it is now at its lowest stage;" or, that "it never falls more than 2 or 3 inches below its present height." At a later visit to the stream in the same season the river surface has been found to be at an elevation 2 or 3 feet below its previous stage. The word of the oldest inhabitant is sometimes fairly reliable as to high water, but his information as to low-water stages should be carefully checked, and the fact that a number of the inhabitants say that the river never goes lower is not sufficient evidence upon which to construct hydraulic works.

Rainfall data are often used in discussing the variation of flow of a stream, and numerous theories and formulas are applied to show that the flow can never fall below a certain amount, these theories to be sadly shaken later, when measurements are made and the facts ascertained. In a few cases greater weight has been given to these theories than to actual measurements, even though the measurements were made by a careful and reliable engineer. The measurements were lower, perhaps, than theory would suggest, and therefore the measurements must be wrong.

In studying the flow of a stream every possible source of information should be utilized—even the ideas of the oldest inhabitants—but to most engineers it is very reassuring to know that actual measure-

ments of the discharge have been made and are available for use. If measurements of the stream under consideration have not been made, then results obtained from measurements of rivers in the immediate vicinity can be used to advantage, care being taken that the hydrographic, topographic, geologic, and forest conditions in the two basins are similar.

As an example of the difficulties under which a prospective investor labors, there are now before the writer reports upon a certain stream in New York State made by five different engineers, all of good standing, in which estimates of the minimum flow of the stream under consideration vary from 0.20 to 0.40 cubic foot per second per square mile; that is, the minimum flow given by one engineer is just twice that given by another. As the development of a water power is limited largely by the low-water flow, the uncertainties arising from such divergent opinions are apparent. Since these reports were made (1900–1901) the flow of this stream has been measured, and the lowest estimate made by the engineers has been shown to be at least 100 per cent too great. In estimates of this kind facts are needed—that is, actual measurements of discharge.

No further discussion is probably necessary to convince most thinking people that the measurement of the larger streams of the United States is an important undertaking, and that capital will be invested in power developments, irrigation, sanitary and other hydraulic works more freely when information as to the flow of the streams is available.

In making measurements of streams it is of course desirable that rapid and economical methods be used, if such are of sufficient accuracy. Methods of stream measurements have been discussed in Water-Supply Paper No. 56, and it is not the purpose of this paper to deal with that question extensively, but rather to point out certain facts developed, during the last few months, by measurements of streams in the southern part of New York State, with the idea that some of the data obtained from these measurements may be useful in studying the flow of other streams and may assist in the selection of methods that will expedite the work and yet give results sufficiently accurate for all practical purposes.

In considering the future demands of the city of New York for water several additional sources of supply have been suggested: Housatonic River, Tenmile River, Wallkill River, Rondout Creek, Esopus Creek, and Catskill Creek, the Hudson River or some of its upper tributaries, Lake George, Lake Champlain, and the Great Lakes. The three last-named sources have been discussed in print somewhat extensively[a] and will not be taken up here. It has been found that the supply from Lake George would not be adequate; that Lake

[a] Report of Merchants' Association of New York on the water supply of the city of New York, August, 1900.

Champlain is at too low an elevation for economical use, and that the supply from the Great Lakes would entail great and unnecessary expense. The water from the Hudson River might be taken near its headwaters and conducted to New York City by a long aqueduct, or the intake might be located just above Poughkeepsie, in which case the water would have to be pumped from the river and filtered before delivery to the city. In either case it is important to know the discharge of the Hudson at various seasons of the year to determine the quantity available and also the effect of the diversion of water upon the regimen of the river.

The United States Geological Survey has for several years been measuring the daily flow of streams throughout the United States, the results of these measurements being used for different purposes, including irrigation, water-power, and sanitary constructions.

Measurements of flow of Schroon River at Warrensburg and of the Hudson at Fort Edward and Mechanicville have been made, also of the Mohawk and its chief tributaries at various points, and the results of these have been published in the annual reports.

The measurements of the rivers discussed in this paper were started at the suggestion of Mr. George N. Birdsall, chief engineer Bureau of Water Supply, New York City, in order that data might be available for investigations as to additional water supply for New York City. The following stations were established by the United States Geological Survey during the summer of 1901 and have been maintained continuously since that time.

Gaging stations on rivers near New York City.

Stream.	Location of gaging station.	Drainage area—		
		Above proposed reservoir.	Above gaging station.	Above mouth.
		Sq. miles.	*Sq. miles.*	*Sq. miles.*
Tenmile River	Dover Plains, N. Y	200	195	195
Housatonic River	Gaylordsville, Conn	1,020	1,020	1,580
Catskill Creek	South Cairo, N. Y	140	260	394
Esopus Creek	Kingston, N. Y	242	312	417
Wallkill River	New Paltz, N. Y	464	735	779
Rondout Creek	Rosendale, N. Y	184	365	[a]369
Fishkill Creek	Glenham, N. Y	158	198	204

[a] Above junction with Wallkill River.

A reconnaissance of each of these streams was made, and stations were selected at points where measurements could be most accurately made, and as far as practicable at points where it was thought knowledge of the flow would be most desired in the future study of these

watersheds as sources of increased supply for New York. The results of the observations at these stations have been published in the Water-Supply Papers of the Survey. The height of the water at each station has been noted twice each day by a local observer and current-meter measurements have been made at frequent intervals by a hydrographer. From these meter measurements a rating curve has been drawn for each station which shows the relation between the height of the water in the river and the discharge. From this curve and the daily mean gage height the flow of the river for each day in the year since the establishment of the station can be determined. These data will be of the greatest importance to the engineers selecting the source of supply, as they furnish the first continuous record of the flow of these streams and give a basis upon which to compute the supply available from each stream, which, with the topographic maps of the survey and the detailed surveys of the reservoir sites, will give complete data for the estimate of the quantity of water that can be furnished by each of these drainage basins and of the relative cost per million gallons of the supply from each.

In addition to the measurement of the discharge, determinations of turbidity, color, alkalinity, and hardness have been made upon each of these streams and are now being continued, and it is thought that these data will prove valuable in the final selection of the new source of supply. Results are given in the Water-Supply Papers of the United States Geological Survey, and are tabulated at the end of this paper.

In making gagings at these stations it was thought desirable to investigate the variations of flow in different parts of the river channel, in order to determine at what points the velocity could be measured to ascertain the mean velocity in the channel without unnecessary expense or loss of time. Before taking up the measurements and the vertical velocity curves constructed, it may not be out of place to describe briefly some of the methods used for the measurement of streams.

METHODS OF MEASURING VELOCITY IN RIVER CHANNELS.

There are in common use a number of methods of measuring the flow of rivers. In general these involve the determination of the mean velocity of the current and the area of the cross section of the stream. The latter is easily computed from soundings made at frequent intervals across the channel. These soundings must be taken at intervals so short that the bottom of the river may be considered a straight line between soundings. Usually the velocity of the current is determined in sections of the river channel, these sections extending between the points of soundings. The summation of the area of each of these sections gives the total area of the cross section. When the

total flow of the river is known and is divided by the area of the cross section the result is called the mean velocity of the river. It is this mean velocity that we try to determine in any method of stream measurement, but, as a matter of fact, it can not be actually determined until the total flow is known.

In the determination of the mean velocity of the current there are a number of methods giving results more or less accurate, all of which should be familiar to the engineer, so that the method best suited to the conditions at hand may be applied.

FLOATS.

GENERAL METHODS.

Floats are frequently employed to determine the velocity of the current. There are three general types in common use: First, surface floats; second, subsurface or double floats; third, tube or rod floats. The general method of procedure is the same whichever form of float is used. The site for making a float measurement should be on a straight reach, having a fairly uniform cross section. The flow of the water should be regular, without sudden rapids or stretches of still water, and should exhibit no tendencies to form eddies or cross currents caused by irregularities in the channel or resulting from the effect of a sharp bend above the reach. The course of the floats should have a length of from 100 to 300 feet, and the areas of cross section at the upper and lower ends of this course should be carefully determined by soundings. When courses more than 100 feet in length are selected, it is desirable that additional cross sections, at equal intervals from one another, should be measured. As a preliminary step, a base line should be laid out by tape on the bank as nearly as possible parallel with the stream, and points should be marked opposite the cross sections to be used. If the stream is not too wide the soundings in the cross sections can be taken most conveniently along a tagged rope stretched across the channel at right angles to the base. If the depth does not exceed 4 feet this can be done by wading, the depth being read on a rod graduated to feet and tenths. Should the depth of the channel or the temperature of the water make wading impossible, a boat may be used. On large rivers, where a tagged rope can not be employed, the boat from which the soundings are to be made should be located by simple triangulation. Soundings should be read to tenths of a foot and be taken preferably at equal distances apart. In deep rivers a tagged rope or chain with lead weight can be substituted for the rod.

SURFACE FLOATS.

In reconnaissance work, in which the equipment is as a rule limited by transportation facilities, surface floats consisting of chips will be found most convenient. The use of rod floats, though giving more

directly the mean velocity, has many disadvantages, and should not be attempted unless the time and opportunity permit of obtaining floats of the required lengths. In the simplest case but one man is needed to make the observations. The surface floats should be thrown into the stream a considerable distance above the first cross section. The hydrographer should attempt to start the floats, successively, at different distances from the shore in order to determine the velocity in different parts of the channel. The time of the passage of each float between the upper and lower cross section should be noted, preferably by a stop watch, and also the position of each float with respect to the tags on the ropes. This will enable the hydrographer to determine whether or not he succeeds in covering the different parts of the stream, and it will serve as an aid in the computation. The observations should be continued until all parts of the stream have been covered.

On wide rivers range poles may be established on opposite shores to mark the upper and lower cross sections. The location of each float as it crosses these imaginary lines can readily be recorded by triangulation. A light traverse plane table will be found especially useful in obtaining a graphic record.

The surface floats show approximately the surface velocity of the stream at the point of measurement. The results obtained by this method are subject to errors due to wind and surface currents and eddies. The velocity shown is that of the surface of the river, while that required for computation of discharge is the mean velocity of the cross section. Unfortunately, the relation of the surface to the mean velocity of the vertical is not constant, yet for streams of the same general character of bed, banks, velocity, etc., the ratio is sufficiently constant to allow the mean velocity to be computed with fair precision from the surface velocity observations.

SUBSURFACE OR DOUBLE FLOATS.

The double float consists of a small surface float connected by a fine cord to a larger subsurface float, which is so arranged that it shall always remain at the point of mean velocity in the current. The surface float may consist of a flat block of wood or a tin water-tight drum, which floats upon the surface of the water with sufficient buoyancy to prevent the larger subsurface float from sinking. The subsurface float may consist of two sheets of galvanized iron set at right angles, weighted at the bottom, with an air-tight cylindrical device at the top, in order that it may at all times keep its vertical position. A round, hollow cylinder of tin also makes an excellent subsurface float. The tension on the connecting cord should be at least 2 or 3 pounds, and the cord should be of silk and as fine as possible in order that its resistance to the current should not have a marked effect upon the velocity of the floats. The length of the cord

should be so regulated that the lower float may be at the point of mean velocity, and the resistance of the upper float and the cord should be made as small as practicable. A small flag should be placed upon the upper float in order that its position may be easily determined at all times. The chief objection to double floats is the uncertainty as to whether the cord is vertical and the consequent uncertainty as to the position of the subsurface float. Another objection is the modifying effect of the surface float and the cord upon the velocity of the lower float, as in great depth the exposed surface of the cord may exceed that of the float. A third objection is the uncertainty as to the vertical position of the lower float, as, owing to changes in depth of water and local conditions, the point of mean velocity may change, whereas the length of the connecting cord must remain constant in each run. This may introduce a noticeable error if the increase in depth is large, as the retarding effect of the slow velocity near the bottom of the river will not be felt by the float, and the result will show too high a velocity. The lower float may tip slightly, owing to eddies or other causes, thereby changing the exposed surface, or, unknown to the observer, the lower float may strike a bowlder, causing its velocity to be checked. In many cases these objections would not be at all serious, but, in general, when floats are to be used better results can be obtained, when the depth is not too great, by the use of rod or tube floats.

ROD OR TUBE FLOATS.

These consist of long, cylindrical tin tubes or wooden poles, 2 or 3 inches in diameter, weighted at the bottom, so that they will float vertically with only 2 or 3 inches exposed above the water surface. These rods integrate the velocities in a vertical section and give approximately the mean velocity of the current. It is important that they should extend nearly to the bottom, as otherwise the velocity, as shown, will be too great, yet the greatest care must be taken that they do not at any time scrape upon the rocks at the bottom or sides so as to retard their movement. Rod floats are free from many of the objections to double floats, as there is no uncertainty as to their position nor as to the point of mean velocity in the channel. They are not, however, suitable for very deep rivers, or for channels where the depth varies considerably, or where weeds grow in the bed of the stream. Mr. James B. Francis has stated that the rod floats travel a little faster than the mean velocity of the water even for the depth of immersion. The float will be subject to pressures proportional to the square of the relative velocities of the water at different points, and when it has attained its full speed there will be equilibrium between these different pressures. This equilibrium may exist, however, when the speed of the float is somewhat different from the mean velocity of the water, the latter being the arithmetical mean of all the different

velocities throughout the depth of immersion. The following formula for correcting an observed velocity was derived by James B. Francis from his Lowell experiments:

$$V_m = V_o\left[1 - .116\left(\sqrt{\frac{d-d'}{d}} - 0.1\right)\right]$$

Where V_m is equal to true mean velocity in vertical, V_o equals observed velocity of tube, d equals mean depth along path of tube, d' equals depth of immersion of tube.

Col. Allan Cunningham[a] has, however, calculated that such floats move somewhat slower than the water in which they are immersed. The error of assuming that the velocity of the tube represents the mean velocity in the vertical will not be material unless tubes too short are used, in which case the velocity as shown by the tube should be somewhat reduced.

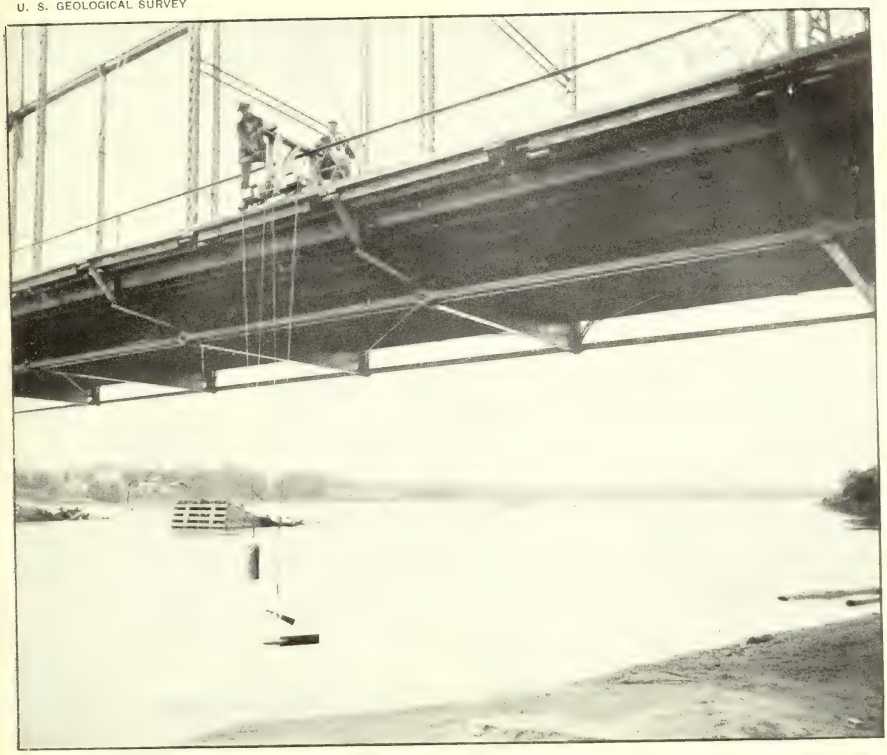
WEIRS.

By the method of weirs the discharge of the stream is computed by means of an empirical formula, which varies for different types of dams or weirs. On creeks or small rivers it is sometimes practicable to build a timber weir across the channel, causing the total flow of the stream to pass over the sharp edge of the weir crest. By observing the head on the weir, computations of the flow can be made. This is probably the most accurate method applicable to small streams. On large rivers, however, the cost of a weir is usually so great as to be prohibitive, so that if there is not a weir or dam already in the stream it is necessary to resort to measurements by floats or current meters.

On many of the rivers of moderate size the conditions are unfavorable for successfully applying either of these methods. For instance, on streams used for manufacturing purposes dams occur at frequent intervals, interrupting the regular flow, and in many cases holding back the night flow for use during the following day, so that the discharge during the night may be either nothing or a very small percentage of the day flow. Then, too, the shutting down of the mill wheels for an hour at noon may have a pronounced effect upon the results of float or meter measurements made below the mill. Unfortunately these variations are not always apparent to the hydrographer, and surprise and annoyance are caused by finding that the river height differs by several tenths from the gage as read by the regular observer a short time before the hydrographer arrived at the station.

Under the conditions described, better results can undoubtedly be obtained if there exists upon the stream a good dam which can be used as a weir. It should have a level, even crest and a constant cross section, with sufficient pondage to reduce the velocity of approach, and it should be free from leakage. Masonry dams are better for

[a] Recent hydraulic experiments: Min. Proc. Inst. Civil Eng., Vol. LXXI 1883.



A. CURRENT METER IN USE, SUSPENDED FROM A BRIDGE.

B. CABLE AND CAR USED TO MEASURE DISCHARGE OF RIVER

this purpose, for they are more likely to be tight and to have an even crest. Timber dams, although level when first constructed, are likely to settle at various points, thus producing an uneven crest elevation. There are, however, many good timber dams practically free from leakage and with crests sufficiently uniform for accurate work.

Having selected a dam as the proper site for a station, a careful survey must be made of the crest line and of the upper and lower slopes, so that it can be compared with other dams or with experimental sections for which the coefficients of flow are known. The experiments of James B. Francis, of Fteley and Stearns, and of John R. Freeman, George W. Rafter, and others at Cornell University, have given coefficients upon many sections of various forms. It is probable that the dam selected for the station will not be exactly like any of the experimental forms, but it will resemble some of them so closely that coefficients can be selected for the computations.

When the mill gates are open a part of the flow is diverted from the river through the mill race, the gates, and the tailrace.

The amount of the diversion must of course be measured and added to the quantity flowing over the dam, in order to determine the total discharge of the stream. In many factories the quantity flowing through the wheels varies from day to day, and also during different hours of the day, so that careful records must be kept of gate openings, in order that proper allowance may be made for these variations. The size and the make of the water wheels must be ascertained, and the wheels be used as water meters for the determination of the flow through them. Many of the modern wheels have been carefully rated. Where such ratings have not been made, usually records of wheels of the same type, though possibly of different makes, can be found and the records be compared. Water wheels as meters give fairly accurate records of the discharge.

The Chezy formula or surface-slope method has been extensively employed in gaging large rivers. The proper coefficients to be applied are usually determined from the auxiliary formula of Gauguillet and Kutter. One difficulty in the application of this method lies in the selection of suitable friction factor or coefficient of roughness.

CURRENT METERS.

The current meter has been found best adapted to the general measurements made by the United States Geological Survey, and is used almost exclusively in its hydrographic investigations. (Pls. I and II.) Occasionally, however, either a meter is not available or the conditions are not favorable for its use. In such cases weirs or floats have been used, though a Pitot's tube, hydrometric pendulum, or hydrometric balance might in exceptional case be used to advantage.

The current meter has been described, and instructions for the care and use of the instrument have been given in Water-Supply Paper

No. 56. The object of the present discussion is to give a few additional facts as to the point at which the meter should be held to determine the mean velocity in a channel, as deduced from measurements recently made upon rivers in the southern part of New York State. The current meter may be used to determine the velocity of a river in four ways: First, by making point measurements at a depth corresponding to the approximate position of the thread of mean velocity; second, by deducing the mean velocity from observations made at other points in the same vertical; third, by the integration method; fourth, by point measurements made at regular intervals throughout cross sections of the river. In the first two of these methods it is important to know the relation between the velocities at various points in the section. In the first method the position of mean velocity must be known, and in the second method the relation between the surface velocity, or the velocity at mean depth, to the mean velocity must be known. In either of these cases the form of the vertical velocity curve will determine the coefficient to be applied to the observations.

VERTICAL VELOCITY CURVES ON STREAMS WITHOUT ICE COVER.

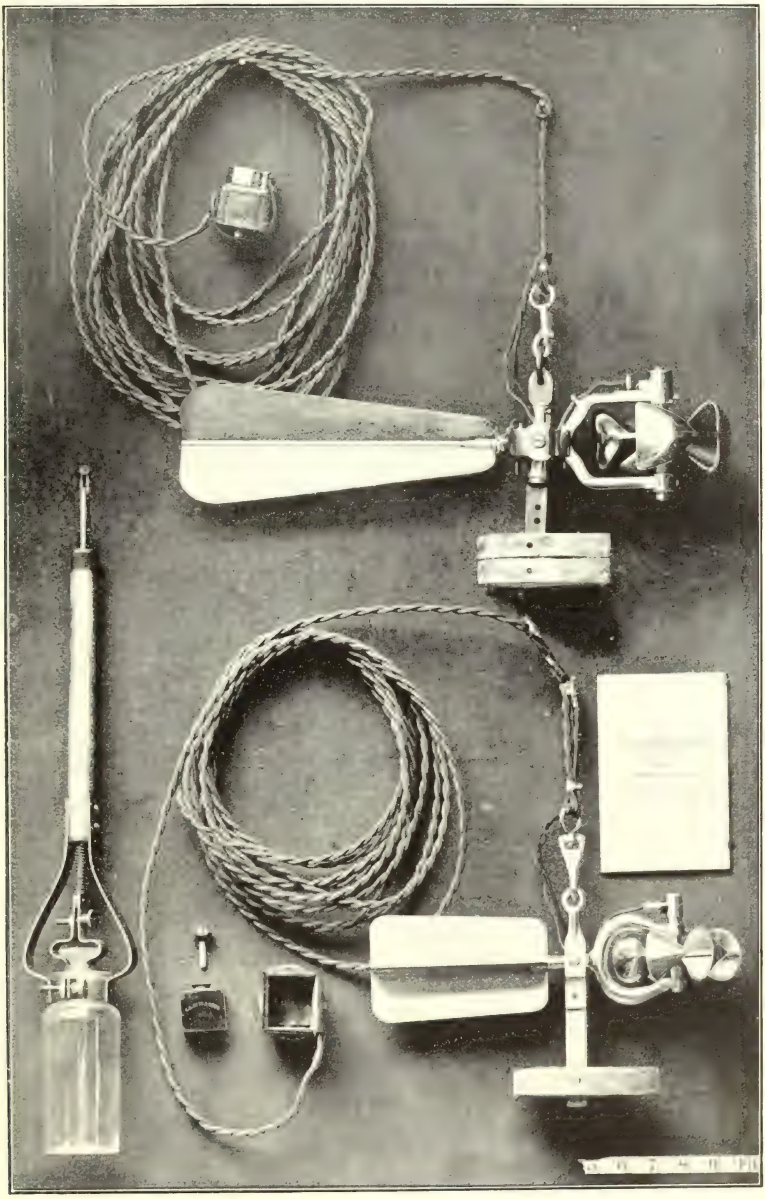
Studies of the vertical velocity curve made on the Mississippi River by Humphreys and Abbott, on the Connecticut by T. G. Ellis, on the Merrimac flume by Wheeler and Lynch, on the Potomac by C. C. Babb, and recent experiments by others, notably those at Cornell University by E. C. Murphy, indicate that the point of mean velocity in a given vertical section is at a depth varying from six-tenths to two-thirds of the total depth of the section, measured from the surface down. The values found in the experiments were as follows:

Depth from surface of point of mean velocity.

Experimenter.	Stream.	Depths.
Cyrus C. Babb	Potomac River	0.58
Humphreys and Abbott	Mississippi River	.63
T. G. Ellis	Connecticut River	.64
E. C. Murphy	Cornell flume	[a].65
Wheeler and Lynch	Merrimac flume	.67

[a] For depths between 6 and 9 feet, the proportionate depth of point of mean velocity becoming less as the depth of the water decreased, and becoming 0.55 for depths of water between 1 and 2 feet.

The Cornell experiments indicate that measurements made at six-tenths of the depth yield results 3.5 per cent too large, the depth of



PRICE ELECTRIC CURRENT METERS.

mean velocity being nearly two-thirds of the depth. The measurements at Cornell were, however, made in the canal, the cross sections of which have a greater ratio of depth to width than most rivers, and decidedly more than the Mississippi, Connecticut, and Potomac, upon which the above coefficients were obtained. There can be no doubt but that the difference in the ratio of the depth to width is a factor likely to affect the position of mean velocity.

The bottom and sides of the channel retard the flow close to them in proportion to their roughness, this retardation being due more to the impeding of the flow by eddies than by friction alone. The retardation of the surface velocity has been attributed to the rising, by vertical motion, of the lower water to the surface after being checked in its flow by striking against the rough bottom and sides of the channel. The variation of the velocity in the river channel is shown in Pl. VIII (p. 30) and fig. 1.

Mr. Frederick P. Stearns has attributed the reduction of surface velocity to the general retarding of the layers of water adjacent to the banks of the stream, this water rising to the surface and thereby making the edges of the channel higher than the center and causing a flow of the slowly moving water from the sides toward the middle, thereby decreasing the surface velocity, depressing the point of maximum velocity, and lowering in general the filament of mean velocity. This depression of the maximum velocity is known to become more pronounced with an increase in the roughness of the lining, in the steepness of the banks, and in the ratio of depth to width. In an extreme case of a wide, shallow stream, where the bottom merges imperceptibly into the banks, maximum velocity occurs, under normal conditions, at or very near the surface of the center of the stream. On the other hand, in a deep, narrow channel, as for instance, in a canal with vertical sides, the maximum velocity occurs a considerable distance below the surface, and, as the Cornell experiments indicate, this depression may amount to as much as one-third and even two-fifths of the total depth. Evidently, then, in such cases depression of maximum velocity must result in a lowering of the thread of mean velocity, and engineers, in making unit measurements for mean velocity, should bear in mind that while the observations at six-tenths depth give fair values for mean velocity in wide, shallow rivers this ratio should be increased to two-thirds in the case of canals and flumes or narrow natural channels.

The friction of flowing water against the air has a similar influence, and, though in general less marked, it may, in the case of a strong upstream wind, have a decided influence upon the surface velocity and the point in the vertical of the maximum and mean velocity. On account of these resistances on the bed and bank of a stream, the maximum velocity of the river in a straight reach is found in the cen-

tral portion of the stream, and somewhat below the surface—the actual position depending upon the size and condition of the river and the velocity of flow. The velocity increases from the surface downward for a short distance—say, one-tenth of the depth—and then decreases down to the bottom, where it reaches the minimum.

Various writers who have studied the form and equation of the curve representing the variation in velocities in a vertical section have

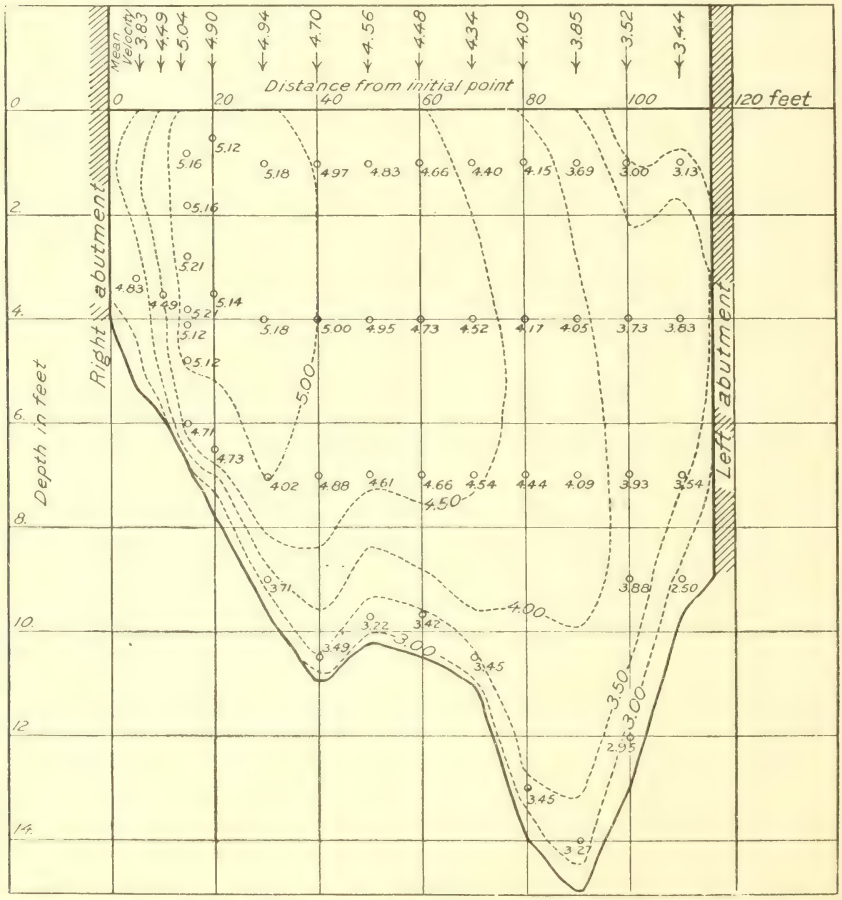


FIG. 1.—Cross section on Esopus Creek, at Kingston, showing curves of equal velocity as determined by current-meter measurements, there being no ice cover.

come to different conclusions as to the form of this curve, the inclined straight line, the parabola with horizontal axis, the parabola with vertical axis and vertex at or below the surface, the ellipse, and the hyperbola each having its advocates. Humphreys and Abbott showed by their experiments on the Mississippi River that the curve did not differ materially from a parabola having its axis parallel to the surface and at the depth below the surface of the position of maximum veloc-

ity, the abscissas representing the velocities at the different depths and the ordinates the vertical distances of these depths from the point of mean maximum velocity. In the Mississippi River experiments the position of maximum velocity was on an average nearly one-third of the whole depth below the surface, varying with the direction of the wind. Bazin also found that the vertical velocity curve was in the form of a parabola, the curve varying with different channels and the position of maximum velocity. Professor von Wagner agreed with the above experimenters, but found that the curve differed from the parabola toward the bottom and near the surface, and that the point of maximum velocity varied from a little below the surface to a little over one-fourth of the full depth.

The exact mathematical form of a vertical velocity curve is not a vital question in the measurement of streams, but it is greatly to be desired that the relation between the surface, maximum, and mean velocities should be known, so that if any one of these be measured accurate computations of the flow can be made, and so that if the velocity of the stream be measured at some particular point the mean velocity of the whole section can be calculated. It has been shown by a series of measurements, the results of which are given herein, that the typical vertical velocity curve is in general of the form shown in fig. 2; that the surface velocity is somewhat greater than the mean; that the maximum velocity is below the surface but above mid depth; and that the point of mean velocity is from 0.6 to two-thirds of the depth below the surface. The relation between the surface velocity and the mean velocity is, of course, important in the use of surface floats and current meters when the velocity is measured only near the surface, for some coefficient must always be applied to obtain the mean velocity in the vertical section. In this connection, some results obtained by Mr. J. B. Lippincott on rivers in southern California, in April, 1902, are of interest:

On the Sacramento River, at Jellys Ferry, observations for velocities have been taken at the top, middle, and bottom of each section at intervals of 20 feet. The channel is of bowlders and has a depth of from 3 to 5 feet in the low-water stages. The relation of the mean velocity to the top velocity on each section was determined, and then the mean ratio for the entire measurement. The measurements were arranged in 6 groups according to gage heights. In the first group the mean velocity was 87 per cent of the surface velocity; in the second 88; in the third 88; in the fourth 89; in the fifth 87; in the sixth 87. The last group represents the highest water. The mean of 30 measurements gives a ratio of 88 per cent. In this case the coefficients are quite constant.

A determination on the Tuolumne River, at Lagrange, also gives a coefficient of 88 per cent. This river has a pebbly or stony bed, and the depths range from 1.12 to 1.84 feet. The velocities range from 3 to 5 feet.

On the smaller rivers the determinations were less satisfactory, because when depths become as low as 1 foot, top, middle, and bottom velocities were seldom observed with meters, and unless we had three observations for velocity the mean

velocity was not considered sufficiently accurate to justify a comparison with the surface velocity.

The relative irregularities of the beds of the smaller streams also introduced wider ranges in the relation of surface to mean velocities.

On the San Gabriel River the following results were obtained at different points on the stream: 0.83, 0.94, 0.95, 0.89, 0.90, 0.98; mean, 0.92.

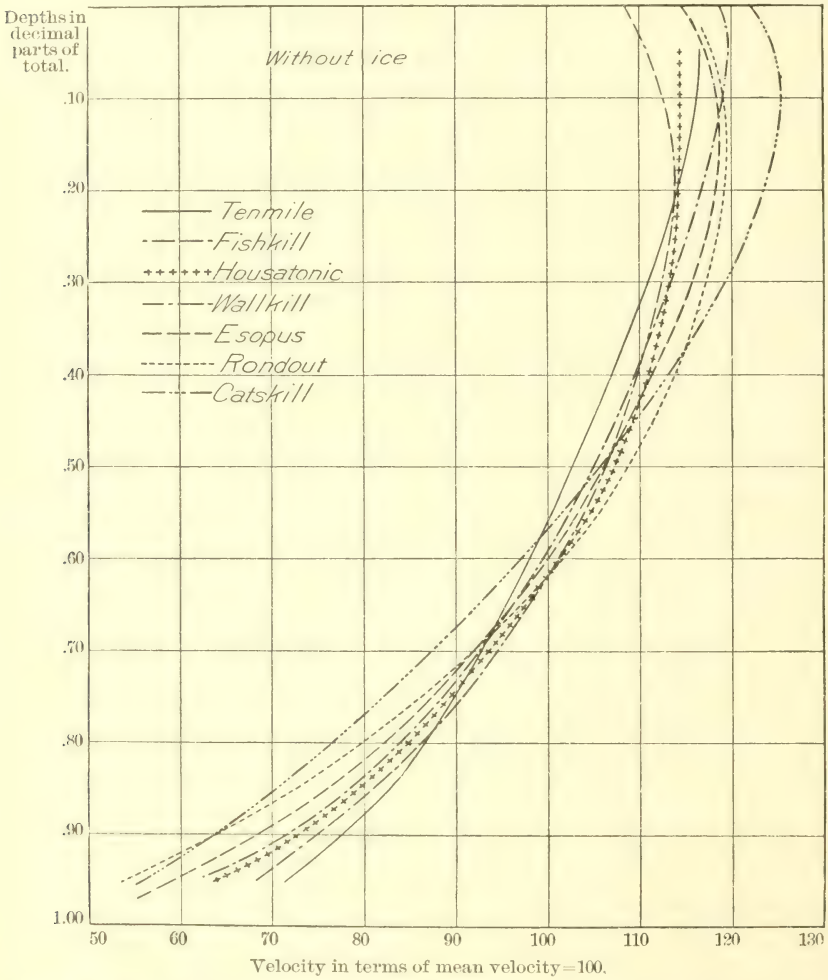


FIG. 2.—Mean vertical velocity curves for Esopus, Rondout, Catskill, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers.

On the Santa Ana River the following determinations were made at Warm Springs: 0.96, 0.95, 0.91, 0.86, 0.90, 0.91, 0.96, 0.93; mean, 0.92.

The channels of these two streams are relatively rough, the water surface is usually from 10 to 20 feet in width, and the depths vary from 0.25 foot to 1 foot for the stage of water observed upon. It is rather singular to note that the determination of these coefficients in the smaller and relatively rough channels shows a higher value than in the larger channels. As previously remarked, how-

ever, the determinations for the San Gabriel and the Santa Ana are not considered as entirely satisfactory nor as reliable as the determination for the Sacramento. It is possible that the coefficients which we have determined for the smaller streams are too high, owing to the fact that the current meter could not be placed in the slowest film of water immediately adjacent to the bottom and sides of the channel, so that the mean velocity as shown may be slightly above the true

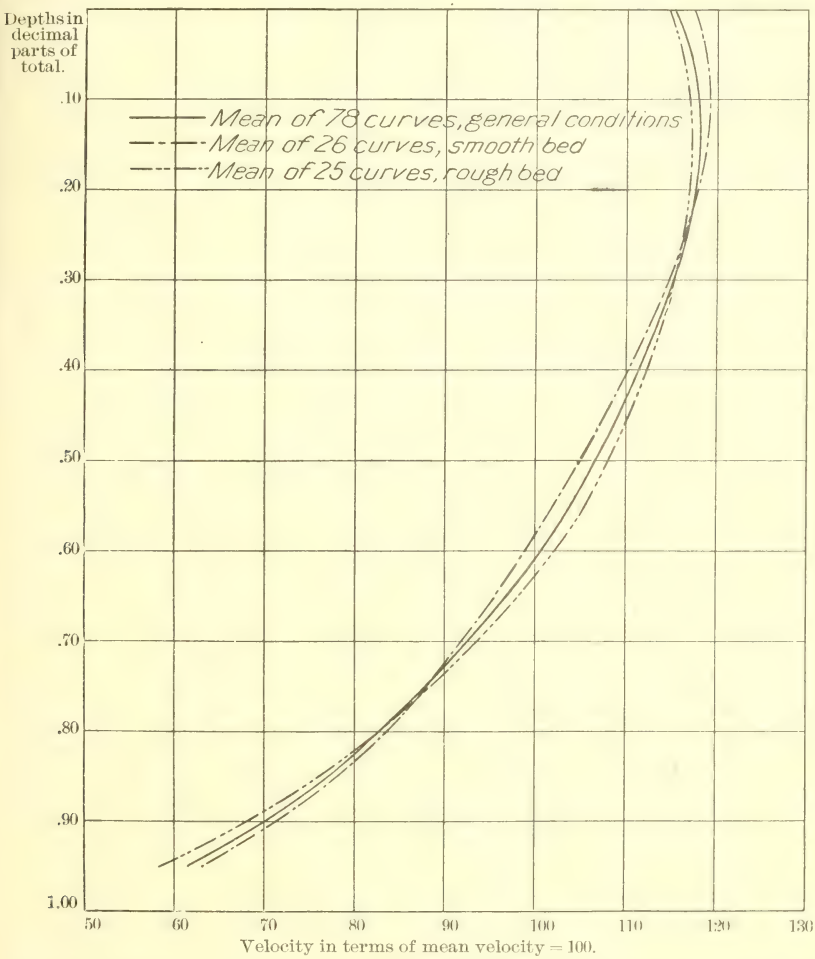


FIG. 3.—Comparison of the general mean velocity curve with the mean curve for smooth bed and the mean curve for rough bed. (Note: The general mean curve includes all data obtained in 78 vertical velocity curves; the mean curve for rough bed includes the data for 25 vertical velocity curves, and the mean curve for smooth bed includes the data for 26 vertical velocity curves. All of these curves were taken when there was no ice cover.)

mean velocity. This error would be relatively greater in small than in large streams, however. In the measurements of the small stream a Price acoustic meter has been used, which permits the center of the meter to be placed within 3 inches of the bed of the creek.

In consideration of the above data it is believed that for ordinary streams discharging 100 cubic feet per second of water, or less, on stony beds, that 0.9 of the

mean surface velocity for the section will represent the mean velocity for that section, said surface velocities being observed at numerous points across the stream.

"With the object of determining the ratio between the maximum surface velocities and the mean velocity, De Prony made some experiments in wooden troughs, and Messrs. Baldwin, Whistler, and Slosson in channels lined with planks. The coefficients obtained for converting the observed surface velocity into mean velocity were 0.816 by De Prony and from 0.810 to 0.847 by the latter observers in different channels. Subsequent experiments indicate that the coefficient is generally comprised within the limits of 0.8 and 0.9, depending upon the size of the channel and the nature of the bed. The Mississippi River experiments show the coefficients to exceed 0.9, but it is quite possible that the influence of the long connecting cord and surface float caused too large values to be recorded for the velocities toward the bottom, and thus gave too high a value to the mean velocity, as Mr. Robert Gordon, in checking his experiments on the Irrawaddi with a current meter, obtained considerable reduction in the velocities approaching the bottom compared with those obtained by double floats. The coefficient would be greatest for large, deep rivers with smooth, uniform channels, and least for small, shallow streams with rough beds. Messrs. Darcy and Bazin derived from their experiments the following formula giving the relation between the maximum velocity and the mean velocity:

$$U - V = 25.36\sqrt{R\,S}$$

where U is the maximum velocity in feet per second, V the mean velocity, R the hydraulic radius in feet, and S the slope.

The variation in the coefficient to be applied to the surface velocity gives rise to a possible error large enough to preclude the use of this method of measurement when accurate results are desired. As a quick method it may often be used, and in a few cases, as, for instance, at the time of high floods, when it is impossible to use other means, the results obtained by this method may be of considerable value.

The mean of 78 velocity curves taken upon rivers in the southern part of New York State, described further on in this paper, shows that the mean velocity was 0.87 of the surface velocity in the vertical section (shown in fig. 3). This coefficient varied from 0.82 in the case of Catskill Creek to 0.93 on Fishkill Creek (fig. 2). It will be noted that these coefficients apply to the mean velocity in the vertical in which the float is run. If only one surface float is used, and that in the center of the river, or point of maximum velocity, it appears that 0.8 is the proper coefficient to apply, though the chances of error are much greater than when surface floats are used at intervals across the channel.

"From Rivers and Canals, vol. 1, p. 38, by L. F. Vernon-Harcourt.

GAGING STATION ON CATSKILL CREEK AT SOUTH CAIRO, N. Y.

GAGING STATION ON ESOPUS CREEK AT KINGSTON, N. Y.

GAGING STATION ON WALLKILL RIVER AT NEW PALTZ, N. Y.

RIVER STATIONS AT WHICH CURVES WERE OBTAINED.

In June, 1901, a reconnaissance was made of Catskill, Esopus, and Rondout creeks, and Wallkill River west of the Hudson, and Fishkill Creek and Tenmile and Housatonic rivers east of the Hudson. Nearly the entire length of each stream was traversed, and a site for a gaging station selected on each. Early in July the stations were established, with the exception of that on Tenmile River, which was established in September of the same year. Persons living near at hand were employed as gage readers to take observations of the stage of the stream twice each day. Mr. A. E. Place was in charge of these stations until September, 1901, when Mr. W. W. Schlecht was placed in charge as resident hydrographer. The measurements given in this paper were obtained by Messrs. Place and Schlecht, and the tables and several of the diagrams were prepared by Mr. Schlecht. The object of the measurements made at these stations was to determine primarily the run-off from the various drainage basins and the availability of the streams as sources of additional supply of water for New York City. The results of the measurements, together with the heights of water in the river on each day, have been published in Water-Supply Paper No. 65. Incidentally it was thought best to make observations as to the point of mean velocity in each of these streams for use in future measurements on the same rivers, as well as for general information as to the most desirable method of making current-meter measurements on rivers in general. In making measurements of rivers of this character it has been the custom of the Hydrographic Division of the United States Geological Survey to divide the cross section into partial areas of regular width, say 5 or 10 feet, and to determine the velocity in each of these small areas by holding the meter at a point six-tenths of the total depth below the surface. The velocity obtained at this point was assumed to be the mean velocity in the small area in which the meter was used. It was realized that this relation would not hold true in all streams, but in rivers with the general characteristics of those under discussion it was considered that no serious error would result from this assumption. The data in the following pages were collected in order to check the above assumption or to enable the hydrographer to determine by a point measurement the velocity at some other depth which might be considered the mean in the channel. Each of the stations established will now be briefly described. The drainage basins were described in detail in Water-Supply Paper No. 65.

CATSKILL CREEK AT SOUTH CAIRO, N. Y.

The gaging station is located at the highway bridge in the village of South Cairo, a view of which is shown on Pl. III. The total span

of the bridge is 194.5 feet between abutments, the faces of which are vertical. The stream bed is of earth for 25 feet from the right abutment. At this point the bluestone rock ledge outcrops, covered with patches of loose shingle and shifting gravel, while the left side of the channel is covered with small gravel. The entire flow of the stream at all stages passes under this bridge. High-water marks at the bridge indicate a maximum elevation of 17.5 feet on the gage. The stage of the stream is observed each morning and evening by the local gage reader, and current-meter measurements are made at intervals by the resident hydrographer.

ESOPUS CREEK AT KINGSTON, N. Y.

This gaging station was established at Washington avenue bridge in Kingston July 5, 1901, a view of which is shown in Pl. IV. This bridge has a clear span of 106.6 feet between abutments, which are nearly vertical. In addition there is on the left side a channel 19 feet in width through which water passes at high stages of the river. Gage readings are made here each morning and evening. The bed is covered with small stone over part of the channel, the rest of the bed being made up of sand, silt, and small gravel.

WALLKILL RIVER AT NEW PALTZ, N. Y.

A gaging station is situated at the New Paltz highway bridge, a view of which is given in Pl. V. The bridge is a span of 146.6 feet between the vertical faces of the masonry abutments. The entire flow passes under this bridge except in extreme freshets, when the left bank is overflowed.

The bed of the river is for the most part smooth, and composed of sand and silt.

RONDOUT CREEK AT ROSENDALE, N. Y.

A gaging station was established at the highway bridge at Rosendale, 3 miles above the junction of the Wallkill, July 6, 1901. The bridge is a single span of 136 feet, and is shown in Pl. VI. The bed of the channel is rock with bowlders for 40 feet from right bank, the rest of the bed being covered with broken rock from 6 inches to 1 foot in diameter. The entire flow, aside from the diversion to the Delaware and Hudson Canal, passes under the bridge at all stages.

FISHKILL CREEK AT GLENHAM, N. Y.

A gaging station is located at the Newburg, Dutchess and Connecticut Railroad bridge, in Glenham. It was established July 8, 1901. The bridge consists of the main central span with two auxil-

GAGING STATION ON RONDOUT CREEK AT ROSENDALE, N. Y.

GAGING STATION ON HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

iary overflow channels at the ends, the length of span being as follows: Left overflow, station zero to 22.5; main span, station 27.5 to station 122; right overflow, station 127 to station 149. The bed of the main channel is earth and gravel; that of the overflow channels is broken stone.

TENMILE RIVER BELOW DOVER PLAINS, N. Y.

A gaging station was established September 16, 1901, at Tabor's bridge, which crosses Tenmile River about 2,000 feet below the point of inflow of Swamp River. The gaging station is situated about 2 miles below Dover Plains Village. Tabor's bridge consists of a single span, 85 feet between abutments. The bridge stands square across the stream, the bed of which is sand and gravel. The entire flow passes between the abutments of this bridge, except at the time of extreme high water, which occurs nearly every spring when the river overflows its banks, and some water passes around one end of the bridge.

HOUSATONIC RIVER AT GAYLORDSVILLE, CONN.

A gaging station was established at Gaylordsville, Conn., October 24, 1900. The station is situated 3 miles east of the New York State line and 2 miles below the mouth of Tenmile River. Owing to the unfavorable conditions under the bridge, the discharge measurements are made from a cable of 200 feet span placed across the stream 1¼ miles below the bridge. A view of the river at this point is shown in Pl. VII. The cable is supported on the right bank by timber shears 25 feet high and is anchored to a large buried rock. On the left bank a sycamore tree serves as a support for the cable, which is anchored to the base of a large oak.

DISCUSSION OF TABLES.

In the tables that are given in the following pages the measurements recorded were taken at the time of the regular gagings of the rivers, and with the same degree of accuracy with which current-meter measurements have been made upon these streams. Only one instrument was used at one time, the velocity being taken at the various points in regular order vertically, usually at intervals of one-half foot. When other space intervals were used it is shown in the tables.

In Pl. VIII is shown the variation in the velocity of Wallkill River at New Paltz. The dotted lines are lines of equal velocities and are determined by observations of velocity at regular intervals throughout

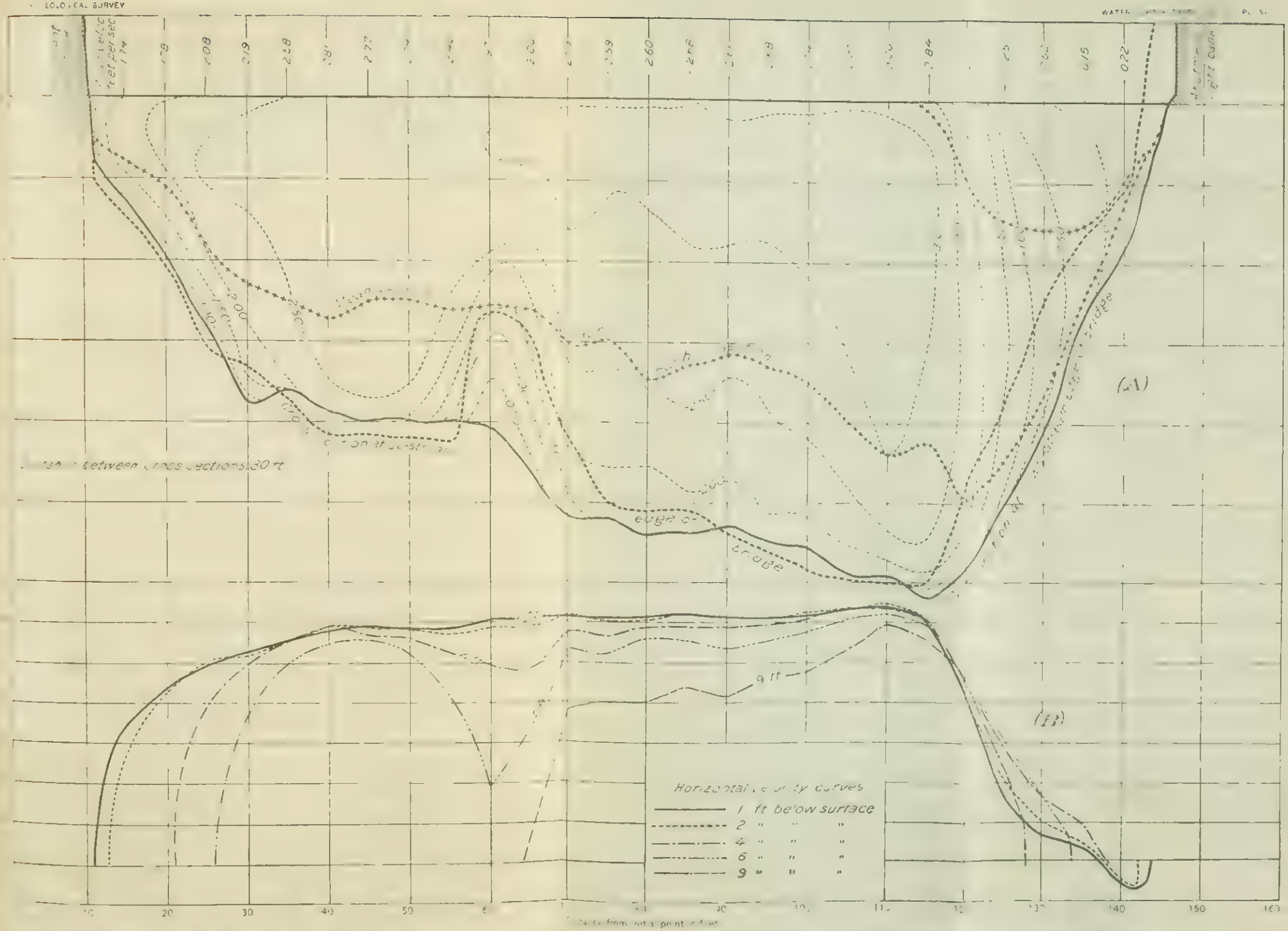
the cross section. The line marked "mean velocity for each section" shows the depth at which may be found the filament of mean velocity. Near the right bank there is slack water and some return current, which accounts for the peculiar position of the curve, and the fact that there are two lines of mean velocity. This condition would not usually occur at a gaging station.

At the bottom of Pl. VIII are lines showing the velocity at various depths, as 1 foot, 2 feet, etc., across the river section. The effect of the ledge of rocks is clearly shown in the plate.

A small Price current meter was used, and was in each case suspended from a bridge and hung freely in the water. The meter was held fifty seconds at one point to determine the velocity, and in each case the first reading was checked by a second, and if there was a discrepancy a third reading was taken. The results were plotted upon cross-section paper, the depths as ordinates and the velocities as abscissas, and a smooth curve drawn through the points, so that in case there was an error of sufficient magnitude to affect the final results it would be found when the curve was plotted. Before the work was commenced, and after the completion of these curves, the meter was rated and showed very slight change in its readings. The gage height was read at the beginning of each measurement and at its completion, and in general no change of stage of the stream during the measurement was noted.

In Table I the date of each measurement is given at the head of the column, then the point of measurement—that is, the distance in feet from the initial point of soundings which had been previously established and marked permanently on the bridge. Next is given the gage height at the time the velocities were measured and the depth of water at the point of measurement at the time of making the measurement. The character of the bed of the river and the force and direction of the wind are also given. The depths, as given in the alternate columns, were measured by a wire attached to the meter and a tape. The column headed "Velocities" gives the actual observed velocity in feet per second at each observation.

Table II is computed from Table I, the observations being the same, but the velocities being given at regular depths as shown in percentages of the whole in the first column. The velocities as shown in the columns of this table were found from the plotted vertical velocity curves based upon the figures in Table I, the velocities at each depth being taken by scale directly from the curve. The sum of the velocities in each column of Table II divided by 10 gives the mean velocity in that section, and is the quantity that should be obtained by a single meter observation at a point in the section which represents the point of mean velocity. For comparison, the velocity as actually found at six-tenths of the depth is given at the bottom of Table II, from which



1. CROSS SECTION OF WALLKILL RIVER AT NEW PALTZ SHOWING CURVES OF EQUAL VELOCITY AS DETERMINED BY CURRENT METER MEASUREMENTS. B. HORIZONTAL VELOCITY CURVES ON WALLKILL RIVER AT NEW PALTZ [illegible] FROM DATA OBTAINED ON THE SAME DATE AS THAT PLOTTED IN A.

it will at once be seen that the error in measuring the velocity at six-tenths depth is in general only slight on a stream of the general character of the Esopus.

Tables III, V, VII, IX, XI, and XIII show the results of the measurements on the Rondout, Wallkill, Catskill, Fishkill, Tenmile, and Housatonic, respectively; Tables IV, VI, VIII, X, XII, and XIV show the data obtained from the preceding tables, and were derived by the same method as Table II from Table I.

TABLE I.—*Velocities in vertical sections on Esopus Creek at Kingston.*

Date	July 19		Aug. 10.		Aug. 19.		Aug. 29.		Aug. 29.		Aug. 29.		Sept. 6.		Sept. 6.		Sept. 21.		Sept. 23.	
Point of measurement	90.		90.		95.		75.		80.		90.		40.		80.		90.		85.	
Gage height	4.40.		4.85.		4.60.		5.50.		5.50.		5.50.		5.46.		5.46.		4.78.		4.55.	
Depth	6.4.		6.2.		5.7.		4.4.		6.1.		7.2.		2.6.		5.3.		6.6.		5.6.	
Bed of river	Silt and gravel.		Silt and gravel.		Silt and sand.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.		Bowlders.		Silt and gravel.		Bowlders.	
Wind force	Strong		Gentle.		Light.		Gentle.		Gentle.		Gentle.		None.		None.		Gentle.		Gentle.	
Direction of wind	Upstream.		Downstream.		Upstream.		Downstream.		Downstream.		Downstream.		.....		.....		Upstream.		Downstream.	
	Depth	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.77	0.2	1.03	0.2	0.82	0.2	1.44	0.2	1.42	0.2	1.31	0.2	1.40	0.2	1.44	0.5	0.85	0.5	0.86
	.9	.77	.7	1.00	.7	.89	.7	1.45	.7	1.54	.7	1.38	.7	1.35	.7	1.47	1.0	.87	1.0	.84
	1.4	.73	1.2	1.03	1.2	.82	1.2	1.38	1.2	1.52	1.7	1.35	1.2	1.07	1.2	1.40	1.5	.87	1.5	.80
	1.9	.71	1.7	1.05	1.7	.86	1.7	1.29	1.7	1.42	2.7	1.24	1.7	1.07	1.7	1.40	2.0	.95	2.0	.85
	2.4	.70	2.2	1.00	2.2	.86	2.2	1.31	2.7	1.40	3.7	1.17	2.1	.96	2.2	1.40	2.5	.85	2.5	.80
	2.9	.66	2.7	.98	2.7	.82	2.7	1.19	3.7	1.05	4.7	.91	.....	.....	2.7	1.38	3.0	.86	3.0	.77
	3.4	.61	3.2	.91	3.2	.75	3.2	1.05	4.7	1.24	5.7	.94	.....	.....	3.7	1.20	3.5	.87	3.4	.75
	3.9	.57	3.7	.86	3.7	.68	3.7	.89	5.6	1.05	6.2	.75	.....	.....	4.2	1.16	4.0	.78	3.5	.72
	4.4	.57	4.2	.77	4.2	.67	3.9	.68	.....	.....	.....	.....	.....	.....	.....	.....	4.5	.70	4.0	.75
	4.9	.48	4.7	.75	4.7	.65	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.0	.65	4.5	.68
	5.4	.54	5.2	.68	5.2	.61	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	.48	5.1	.47
	5.9	.51	5.7	.63	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.1	.40	.....	.....

Date	Oct. 16.		Oct. 16.		Oct. 21.		Nov. 1.		Nov. 1.		Nov. 18.		Nov. 18.		Nov. 18.		Nov. 26.		Nov. 26.	
Point of measurement	40.		90.		90.		80.		95.		77.		87.		97.		95.		90.	
Gage height	6.64.		6.64.		5.56.		4.74.		4.74.		4.45.		4.45.		4.45.		5.06.		5.06.	
Depth	4.0.		8.6.		7.4.		5.0.		5.9.		4.4.		6.0.		5.0.		6.0.		6.8.	
Bed of river	Bowlders.		Silt and gravel.		Silt and gravel.		Bowlders.		Silt and sand.		Bowlders.		Silt and gravel.		Silt.		Silt.		Silt and gravel.	
Wind force	None.		None.		Gentle.		None.		None.		Gentle.		Gentle.		Gentle.		Gale.		Gale.	
Direction of wind	.....		.....		Upstream.		.....		.....		Upstream.		Upstream.		Upstream.		Downstream.		Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.5	2.26	0.5	1.89	0.5	1.42	0.5	0.98	0.5	0.85	0.5	0.85	0.5	0.80	0.3	0.67	0.5	0.97	0.5	1.04
	1.5	2.29	1.5	1.86	1.5	1.37	1.5	.92	1.5	.82	1.5	.82	1.5	.80	.8	.70	1.5	.97	1.5	1.05
	2.4	2.12	2.5	1.86	2.5	1.32	2.5	.91	2.5	.71	2.5	.77	2.5	.77	1.7	.67	2.5	.84	2.5	.91
	2.5	2.07	3.5	1.79	3.5	1.22	3.0	.91	3.5	.67	2.6	.76	3.5	.62	2.7	.57	3.6	.80	4.1	.82
	3.0	1.52	4.5	1.74	4.4	1.10	3.5	.87	3.5	.66	3.5	.60	3.6	.65	3.0	.52	4.5	.70	5.0	.67
	3.5	1.25	5.2	1.65	4.5	1.07	4.5	.60	4.5	.62	3.8	.46	4.5	.62	3.7	.51	5.5	.60	6.3	.51
	.....	.....	5.5	1.57	5.5	.97	.....	.....	5.4	.42	.....	.....	5.5	.47	4.5	.27	.....	.....	.....	.....
	.....	.....	6.5	1.42	6.5	.85	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	7.5	1.22	7.0	.72	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	8.1	1.15	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE II.—*Velocities at regular intervals in vertical sections on Esopus Creek, deduced from data in Table I.*

[Velocities in feet per second.]

Depth in parts of total.	July 19.	Aug. 10.	Aug. 19.	Aug. 29.	Aug. 29.	Aug. 29.	Sept. 6.	Sept. 6.	Sept. 21.	Sept. 26.	Oct. 16.	Oct. 16.	Oct. 21.	Nov. 1.	Nov. 1.	Nov. 18.	Nov. 18.	Nov. 18.	Nov. 26.	Nov. 26.
0.05	0.77	1.02	0.83	1.45	1.48	1.34	1.40	1.45	0.85	0.83	2.24	1.88	1.41	0.97	0.84	0.85	0.79	0.67	0.97	1.03
.15	.76	1.04	.87	1.44	1.51	1.38	1.38	1.46	.88	.84	2.28	1.89	1.42	.97	.85	.85	.82	.70	.98	1.04
.25	.74	1.05	.87	1.41	1.47	1.35	1.35	1.44	.90	.85	2.30	1.87	1.37	.96	.82	.84	.81	.69	.95	1.01
.35	.71	1.02	.85	1.36	1.42	1.29	1.29	1.42	.89	.83	2.29	1.84	1.30	.94	.78	.82	.78	.67	.92	.97
.45	.68	.96	.82	1.29	1.37	1.21	1.22	1.40	.86	.81	2.26	1.77	1.23	.92	.74	.80	.74	.63	.87	.92
.55	.64	.90	.77	1.22	1.30	1.13	1.64	1.37	.81	.78	2.17	1.68	1.15	.90	.68	.77	.69	.58	.92	.85
.65	.60	.83	.72	1.14	1.22	1.04	1.06	1.32	.73	.74	2.00	1.56	1.06	.87	.63	.73	.64	.52	.77	.77
.75	.56	.76	.66	1.02	1.14	.94	.98	1.25	.63	.68	1.70	1.44	.96	.83	.57	.66	.58	.44	.72	.68
.85	.52	.68	.60	.85	1.05	.83	.89	1.17	.48	.58	1.39	1.29	.85	.69	.49	.54	.52	.35	.65	.58
.95	.43	.60	.51	.56	.94	.69	.79	1.02	.27	.36	.97	1.08	.65	.45	.40	.34	.43	.25	.55	.45
Mean	.64	.89	.75	1.17	1.29	1.12	1.15	1.33	.73	.73	1.96	1.63	1.14	.85	.68	.72	.68	.55	.82	.83
.60	.63	.87	.75	1.18	1.26	1.09	1.11	1.34	.77	.76	2.08	1.63	1.11	.88	.66	.75	.67	.55	.80	.81

Character of the bed: From station 0 to 86 broken rock from 0.5 feet to 1.0 foot in diameter. From station 86 to 105 smooth and even bed, composed of sand, silt, and small gravel. From 105 to 116 broken rock 0.5 feet to 1.0 foot in diameter.

TABLE III.—*Velocities in vertical sections on Rondout Creek at Rosendale.*

Date	Aug. 8.		Aug. 8.		Aug. 8.		Sept. 4.		Sept. 24		Oct. 11.		Oct. 11.		Oct. 11.		Oct. 18.		Nov. 7.		Nov. 16.		Nov. 26.		Dec. 21.	
Point of measurement	90.		105.		45.		35.		75.		65.		75.		85.		65.		80.		70.		65.		70.	
Gage height	7.50.		7.50.		7.15.		7.55.		6.45.		6.47.		6.47.		6.47.		7.03.		6.42.		6.55.		7.21.		7.60.	
Depth	7.2.		5.9.		5.2.		4.7.		5.6.		5.6.		5.6.		6.2.		6.3.		6.2.		5.6.		6.6.		6.4.	
Bed of creek	Bowlders.		Bowlders.		Bowlders.		Rock.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.		Bowlders.	
Wind force	None.		None.		None.		Gentle.		Gentle.		Gentle.		Gentle.		Gentle.		Strong.		Gentle.		Strong.		None.		Gentle.	
Direction of wind							Down-stream.		Down-stream.		Up-stream.		Up-stream.		Up-stream.		Down-stream.		Up-stream.		Down-stream.				Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*	*Ft.*	*Feet per sec.*
	0.2	1.70	0.2	1.33	0.2	1.29	0.2	1.58	0.3	0.51	0.5	0.55	0.5	0.60	0.8	0.52	0.3	1.41	0.5	0.48	0.5	0.65	0.5	7.76	3.5	1.94
	.7	1.60	1.2	1.42	.7	1.40	1.2	1.52	1.0	.52	1.5	.52	1.5	.55	1.8	.50	.5	1.42	1.5	.46	1.5	.65	1.5	1.71	1.5	1.96
	1.2	1.65	2.2	1.22	1.2	1.42	2.2	1.49	2.0	.50	2.5	.52	2.5	.47	2.8	.50	1.5	1.42	2.5	.45	2.5	.60	2.5	1.70	2.5	1.89
	2.2	1.54	3.2	1.24	1.7	1.44	3.2	1.44	3.0	.47	3.4	.45	3.4	.47	3.7	.45	2.5	1.37	3.5	.43	3.4	.56	3.5	1.69	3.5	1.77
	3.2	1.33	4.2	1.05	2.2	1.40	4.2	1.19	3.4	.46	3.5	.40	3.5	.42	3.7	.45	3.5	1.35	3.7	.45	3.5	.50	4.0	1.70	3.8	1.70
	4.0	1.29	5.2	.75	3.2	1.14	.....	.....	4.0	.43	4.5	.32	4.3	.35	4.7	.40	3.8	1.22	4.6	.32	4.5	.32	5.0	1.30	1.5	1.50
	4.2	1.24	.....	.....	4.2	.89	.....	.....	5.1	.30	5.1	.37	5.1	.25	5.7	.22	4.5	1.07	5.6	.20	5.0	.20	4.0	1.04	5.5	.80
	5.2	1.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.5	.82	.....	.....	.....	.....	.....	.....	5.9	.62
	6.2	.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	5.8	5.2	.....	.....	.....	.....	.....	.....	.....	.....
	6.7	.86	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE IV.—*Velocities at regular intervals in vertical sections on Rondout Creek at Rosendale, deduced from data in Table III.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 8.	Aug. 8.	Aug. 8.	Sept. 4.	Sept. 24.	Oct. 11.	Oct. 11.	Oct. 11.	Oct. 18.	Nov. 7.	Nov. 16.	Nov. 26.	Dec. 21.
0.05	1.65	1.36	1.33	1.57	0.51	0.55	0.58	0.50	1.41	0.46	0.65	1.75	1.93
.15	1.66	1.39	1.40	1.57	.52	.55	.57	.52	1.42	.47	.65	1.76	1.97
.25	1.59	1.37	1.43	1.55	.52	.54	.56	.51	1.41	.47	.65	1.75	1.96
.35	1.59	1.34	1.40	1.53	.51	52	.54	.50	1.40	.47	.63	1.73	1.93
.45	1.40	1.28	1.33	1.50	.49	.50	.52	.49	1.37	.46	.60	1.70	1.86
.55	1.29	1.21	1.23	1.47	.47	.46	.48	.47	1.30	.43	.55	1.66	1.77
.65	1.18	1.11	1.10	1.42	.44	.41	.44	.43	1.20	.39	.49	1.53	1.60
.75	1.07	.99	.97	1.35	.40	.36	.37	.39	1.08	.34	.39	1.37	1.35
.85	.95	.82	.83	1.28	.34	.30	.29	.32	.92	.28	.28	1.17	1.02
.95	.81	.63	.68	1.16	.26	.21	.20	.17	.59	.18	.17	.88	.61
Mean	1.31	1.15	1.17	1.44	.44	.44	.45	.43	1.21	.40	.51	1.53	1.60
.60	1.24	1.16	1.17	1.45	.46	.44	.46	.45	1.25	.41	.52	1.60	1.69

Character of bed: From station 0 to 40, rock bed with some bowlders; from station 40 to bank, broken rock from 0.5′ to 1′ in diameter.

TABLE V.—*Velocities in vertical sections on Wallkill River at New Paltz.*

Date	Aug. 10.		Oct. 1.		Oct. 9.		Oct. 24.		Oct. 24.		Nov. 9.		Nov. 16.		Nov. 16.		Nov. 16.	
Point of measurement	70.		70.		105.		80.		105.		90.		105.		90.		80.	
Gage height	10.0.		7.36.		6.48.		6.33.		6.33.		5.94.		6.50.		6.50.		6.50.	
Depth	9.8.		7.5.		7.8.		6.4.		7.6.		6.2.		7.8.		6.6.		6.4.	
Bed of river	Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.		Silt.	
Wind force	Gentle.		Gentle.		Fresh.		Fresh.		Fresh.		Gentle.		Fresh.		Fresh.		Fresh.	
Direction	Downstream.		Downstream.		Downstream.		Upstream.		Upstream.		Downstream.		Downstream.		Downstream.		Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	3.00	0.3	1.79	0.5	1.22	0.3	0.89	0.5	0.95	0.5	0.62	0.5	1.21	0.5	1.20	0.5	1.16
	1.0	3.05	1.3	1.70	1.5	1.15	0.8	.91	1.5	.97	1.5	.55	1.5	1.11	1.5	1.17	2.0	1.05
	2.0	2.77	2.3	1.67	2.5	1.12	1.5	.86	2.5	.92	2.5	.50	2.5	1.05	2.5	1.05	3.0	.92
	3.0	2.91	3.3	1.60	3.5	1.12	2.5	.77	3.5	.95	3.5	.42	3.5	1.05	3.5	.89	3.8	.90
	4.0	2.86	4.3	1.50	4.5	1.08	3.5	.70	4.5	.92	3.7	.46	4.5	1.05	4.0	.91	5.0	.72
	5.0	2.86	4.5	1.52	4.7	1.05	3.8	.75	4.6	.92	4.5	.36	4.7	1.07	4.5	.81	5.9	.66
	6.0	2.58	5.3	1.40	5.5	.97	4.5	.65	5.5	.82	5.7	.23	5.5	.91	5.5	.62	.....	.....
	7.0	2.47	6.3	1.32	6.5	.87	5.5	.47	6.5	.73	.....	.....	6.5	.80	6.1	.54	.....	.....
	8.0	2.35	6.9	1.15	7.3	.50	5.8	.37	7.1	.60	.....	.....	7.3	.60	.....	.....	.....	.....
	9.0	1.98	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VI.—*Velocities at regular intervals in vertical sections on Wallkill River at New Paltz, deduced from data in Table V.*

[Velocities in feet per second.]

Depth in parts of total.	Aug. 20.	Oct. 1.	Oct. 9.	Oct. 24.	Oct. 24.	Nov. 9.	Nov. 16.	Nov. 16.	Nov. 16.
0.05	3.00	1.77	1.23	0.90	0.94	0.62	1.20	1.20	1.16
.15	3.04	1.75	1.18	.90	.97	.59	1.15	1.18	1.13
.25	2.99	1.70	1.14	.87	.97	.56	1.13	1.15	1.08
.35	2.91	1.65	1.12	.83	.96	.53	1.10	1.08	1.03
.45	2.82	1.59	1.10	.79	.94	.49	1.07	1.01	.97
.55	2.72	1.52	1.07	.75	.92	.45	1.02	.93	.91
.65	2.60	1.45	1.03	.69	.86	.40	.97	.83	.84
.75	2.44	1.37	.95	.63	.80	.35	.90	.73	.77
.85	2.20	1.27	.82	.53	.71	.30	.77	.61	.68
.95	1.88	1.13	.46	.35	.53	.24	.49	.48	.58
Mean	2.66	1.52	1.01	.724	.86	.453	.98	.92	.91
.60	2.66	1.49	1.05	.72	.89	.43	1.00	.88	.88

Character of bed of stream: At all of the above stations the bed of the creek is smooth, composed of sand and silt.

TABLE VII.—*Velocities in vertical sections on Catskill Creek at South Cairo.*

Date	July 20		July 25		July 25		Aug. 1.		Aug. 1.		Aug. 9.		Aug. 23.		Sept. 2.		Sept. 2.		Sept. 7.		Sept. 23.		Oct. 22.		Nov. 8.		Sept. 2.	
Point of measurement	55.		55.		45.		55,		60.		50.		60.		35.		40.		35.		55.		30.		50.		60.	
Gage height	3.60.		3.00.		3.00.		2.80.		2.80.		3.00.		3.12.		3.00.		3.00.		2.92.		2.74.		2.82.		2.70.		3.00.	
Depth	3.6.		2.9.		3.6.		2.7.		2.7.		3.1.		2.9.		4.4.		3.9.		4.3.		2.7.		2.3.		2.9.		3.0.	
Bed of creek	Rock.		Rock.		Rock.		Rock.		Gravel.		Rock.		Gravel.		Gravel.		Gravel.		Rock.		Gravel.		Rock.		Rock.		Gravel.	
Wind force	None.		Gentle.		Gentle.		Strong.		Strong.		Gentle.		Gentle.		Gentle.		Gentle.		.....		.....		.....		Fresh.		Gentle.	
Direction	.....		Down-stream.		Down-stream.		Down-stream.		Down-stream.		Up-stream.		Down-stream.		Up-stream.		Up-stream.		None.		None.		None.		Down-stream.		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
0.2	1.67	0.2	0.75	0.2	0.66	0.2	0.52	0.2	0.48	0.2	0.61	0.3	1.05	0.2	0.61	0.2	0.73	0.2	0.48	0.2	0.48	0.2	0.37	0.5	0.37	0.2	0.77
.5	1.72	.5	.77	.5	.63	.5	.50	.5	.48	.7	.67	.8	1.03	.7	.59	.7	.71	.7	.50	.7	.42	.7	.36	1.0	.35	.6	.75
1.0	1.54	1.0	.75	1.0	.66	1.0	.45	1.0	.43	1.2	.66	1.3	.99	1.2	.52	1.2	.69	1.2	.41	1.2	.35	1.2	.32	1.5	.30	1.1	.73
1.5	1.52	1.5	.63	1.5	.57	1.5	.43	1.5	.36	1.7	.59	1.8	.73	1.7	.50	1.7	.61	1.7	.43	1.6	.35	1.4	.31	1.7	.31	1.6	.54
2.0	1.47	1.7	.59	2.0	.57	1.6	.43	1.6	.38	2.0	.50	2.3	.57	2.2	.43	2.2	.63	2.7	.29	1.7	.25	1.8	.27	2.0	.28	2.1	.54
2.5	1.21	2.0	.52	2.2	.61	2.0	.36	2.0	.25	2.2	.54	2.8	.34	2.7	.38	2.7	.61	3.8	.23	2.2	.17	.....	.....	2.4	.25	2.6	.36
3.0	1.07	2.4	.45	2.5	.50	2.2	.25	2.2	.25	2.7	.54	.....	.....	3.2	.29	3.2	.58	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
3.1	1.13	.....	.....	3.0	.50	.....	.....	.....	.....	.....	.....	.....	.....	3.7	.22	3.7	.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE VIII.—*Velocities at regular intervals in vertical sections on Catskill Creek at South Cairo, deduced from data in Table VII.*

[Velocities in feet per second.]

Depth in parts of total.	July 20.	July 25.	July 25.	Aug. 1.	Aug. 1.	Aug. 9.	Aug. 23.	Sept. 2.	Sept. 2.	Sept. 7.	Sept. 23.	Oct. 22.	Nov. 8.	Sept. 2.
0.05	1.69	0.75	0.64	0.52	0.48	0.65	1.06	0.60	0.72	0.48	0.47	0.37	0.37	0.77
.15	1.70	.76	.65	.51	.49	.68	1.05	.59	.71	.49	.44	.38	.37	.76
.25	1.65	.76	.65	.50	.47	.68	1.03	.56	.70	.46	.41	.37	.36	.75
.35	1.58	.73	.63	.48	.44	.67	.98	.51	.68	.43	.38	.36	.35	.73
.45	1.50	.68	.60	.45	.41	.65	.92	.46	.66	.39	.35	.34	.33	.68
.55	1.41	.62	.57	.42	.37	.61	.84	.40	.64	.35	.32	.32	.31	.61
.65	1.32	.56	.54	.38	.32	.57	.74	.34	.62	.31	.28	.30	.29	.53
.75	1.21	.50	.50	.32	.27	.52	.62	.28	.59	.26	.23	.28	.26	.45
.85	1.10	.43	.46	.26	.21	.47	.50	.22	.56	.20	.17	.25	.23	.37
.95	.94	.36	.40	.18	.14	.40	.36	.14	.52	.13	.10	.19	.19	.25
Mean	1.41	.61	.564	.40	.36	.59	.81	.41	.64	.35	.31	.31	.31	.59
.60	1.37	.59	.56	.40	.35	.59	.80	.37	.63	.33	.30	.31	.30	.57

Character of river bed: From station 0 to 55 the bed is a rock ledge, and from station 55 to the left bank it is small gravel, none over 0.2 foot in diameter.

TABLE IX.—*Velocities in vertical sections on Fishkill Creek at Glenham.*

Date	July 24.		Aug. 15.		Aug. 15.		Aug. 30.		Aug. 30.		Aug. 30.		Sept. 6.		Sept. 6.		Sept. 27.		Oct. 5.		Oct. 25.		Nov. 11.		Nov. 20.	
Point of measurement	51.		50.		55.		45.		50.		55.		60.		65.		75.		55.		85.		55.		50.	
Gage height, feet	3.60.		3.85.		3.85.		4.60.		4.60.		4.60.		4.15.		4.15.		3.86.		3.98.		4.05.		3.85.		3.95.	
Depth	3.6.		4.0.		3.4.		4.4.		4.4.		4.2.		3.8.		3.2.		2.9.		3.5.		2.8.		3.4.		4.0.	
Bed of creek	Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.		Gravel.	
Wind	Gentle.		Strong.		Strong.		Gentle.		Gentle.		Gentle.		None.		None.		Gentle.		Gentle.		Fresh.		None.		Gentle.	
Direction	Up-stream.		Down-stream.		Down-stream.		Down-stream.		Down-stream.		Down-stream.		.....		.....		Down-stream.		Down-stream.		Up-stream.		.....		Up-stream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.2	0.54	0.2	0.75	0.2	0.73	0.2	1.70	0.2	1.42	0.2	1.47	0.2	1.05	0.2	1.21	0.3	0.66	0.4	0.93	0.3	1.05	0.4	0.62	0.5	0.69
	.7	.54	.7	.75	.7	.75	.7	1.89	.7	1.77	.7	1.75	7	1.17	.7	1.24	.8	.64	.9	.90	.8	1.02	9	.60	1.0	.64
	1.2	.45	1.2	.73	1.2	.71	1.2	1.87	1.2	1.75	1.2	1.70	1.2	1.17	1.2	1.17	1.3	.61	1.4	.87	1.3	.97	1.9	.56	1.7	.65
	1.7	.38	1.7	.68	1.7	.68	1.7	1.96	1.7	1.72	1.7	1.67	1.7	1.14	1.7	1.14	1.7	.56	1.9	.87	1.7	.97	2.0	.57	2.4	.65
	2.2	.38	2.2	.66	2.2	.63	2.2	1.79	2.2	1.67	2.2	1.61	2.2	1.03	2.2	.98	1.8	.57	2.1	.85	2.3	.67	2.9	.42	2.9	.59
	2.7	.29	2.4	.66	2.7	.59	2.7	1.75	2.7	1.61	2.7	1.54	2.7	.94	2.9	.50	2.3	.46	2.5	.85	.....	.....	.....	.....	3.5	.54
	3.1	.27	2.7	.54	.....	.....	3.2	1.61	3.2	1.52	3.2	1.54	3.3	.73	.....	.....	.....	.....	3.0	.70	.....	.....	.....	.....	.....	.....
	.....	.....	3.2	.45	.....	.....	3.7	1.49	3.7	1.30	3.7	1.38	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	.....	.....	.....	.....	.....	.....	3.9	1.29	3.9	1.03	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

TABLE X.—*Velocities at regular intervals in vertical sections on Fishkill Creek at Glenham, deduced from data in Table IX.*

[Velocities in feet per second.]

Depths in parts of total.	July 24.	Aug. 15.	Aug. 15.	Aug. 30.	Aug. 30.	Aug. 30.	Sept. 6.	Sept. 6.	Sept. 27.	Oct. 5.	Oct. 25.	Nov. 11.	Nov. 20.
0.05	0.54	0.75	0.74	1.77	1.64	1.63	1.06	1.21	0.67	0.95	1.05	0.62	0.67
.15	.54	.75	.75	1.87	1.74	1.71	1.15	1.22	.66	.93	1.05	.62	.68
.25	.51	.74	.74	1.92	1.75	1.71	1.18	1.21	.65	.90	1.04	.61	.67
.35	.47	.72	.72	1.91	1.73	1.68	1.16	1.19	.63	.88	1.02	.60	.66
.45	.43	.68	.70	1.86	1.69	1.64	1.12	1.16	.61	.87	1.00	.59	.65
.55	.39	.63	.67	1.78	1.64	1.60	1.06	1.11	.58	.86	.97	.57	.64
.65	.34	.56	.63	1.69	1.58	1.56	.98	1.02	.55	.85	.89	.54	.62
.75	.29	.48	.59	1.59	1.50	1.51	.88	.88	.52	.81	.80	.50	.58
.85	.23	.40	.55	1.45	1.38	1.44	.76	.70	.45	.75	.67	.44	.54
.95	.16	.30	.51	1.26	1.15	1.32	.62	.50	.35	.65	.53	.35	.49
Mean	.39	.60	.66	1.71	1.58	1.58	1.00	1.02	.57	.85	.90	.54	.62
.60	.37	.60	.65	1.74	1.61	1.58	1.02	1.07	.57	.86	.93	.56	.63

Character of bed of creek: Bowlders from 0.2 foot to 0.6 foot in diameter.

TABLE XI.—*Velocities in vertical sections on Tenmile River at Dover Plains.*

Date	Oct. 15.		Oct. 26.		Oct. 26.		Nov. 11.		Nov. 22.	
Point of measurement	55.		25.		55.		25.		25.	
Gage height	7.19.		5.01.		5.01.		4.75.		4.76.	
Depth	6.8.		4.6.		4.8		4.4.		4.2.	
Bed of creek	Sand.		Sand.		Sand.		Sand.		Sand.	
Wind	Fresh.		None.		None.		None.		Gentle.	
Direction	Downstream.								Downstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	2.43	0.3	1.10	0.5	1.00	0.4	0.90	0.3	0.84
	1.5	2.38	.8	1.07	1.5	.95	.9	.87	.8	.84
	2.5	2.31	1.3	1.00	2.5	.93	1.4	.77	1.5	.73
	3.5	2.19	1.8	.92	2.9	.92	2.0	.70	2.0	.75
	4.1	2.17	2.3	.90	3.5	.90	2.6	.67	2.5	.67
	4.4	2.09	2.8	.82	4.3	.77	3.0	.61	3.0	.56
	5.3	2.00	3.3	.75			3.5	.55	3.5	.55
	6.3	1.84	4.1	.62			3.9	.50	3.7	.49

TABLE XII.—*Velocities at regular intervals in vertical sections on Tenmile River at Dover Plains, deduced from data in Table XI.*

[Velocities in feet per second.]

Depths in parts of total.	Oct. 15.	Oct. 26.	Oct. 26.	Nov. 11.	Nov. 22.
0.05	2.44	1.08	0.99	0.89	0.84
.15	2.42	1.06	.99	.86	.84
.25	2.36	1.03	.98	.83	.82
.35	2.30	.98	.97	.79	.78
.45	2.23	.93	.95	.75	.74
.55	2.16	.87	.93	.70	.70
.65	2.09	.81	.91	.64	.65
.75	2.02	.73	.88	.58	.59
.85	1.95	.65	.82	.52	.51
.95	1.83	.46	.68	.44	.43
Mean	2.18	.86	.91	.70	.69
.60	2.13	.84	.92	.67	.68

TABLE XIII.—*Velocities in vertical sections on Housatonic River at Gaylordsville.*

Date	Aug. 8.		Oct. 29.		Nov. 13.		Nov. 23.	
Point of measurement	60.		60.		60.		60.	
Gage height	3.50.		4.05.		4.82.		4.11.	
Depth	3.8.		4.8.		6.2.		4.8.	
Bed of creek	Gravel.		Gravel.		Gravel.		Gravel.	
Wind	None.		None.		Very strong.		Gentle.	
Direction					Downstream.		Upstream.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.20	2.19	0.5	2.98	0.5	3.84	0.5	3.03
	.30	2.23	1.5	2.90	1.5	3.93	1.5	2.92
	.8	2.25	2.5	2.85	2.5	3.84	2.5	2.81
	1.3	2.14	2.9	2.68	3.5	3.50	2.9	2.61
	1.8	2.07	3.5	2.39	3.7	3.44	3.5	2.38
	2.3	2.05	4.3	1.92	4.5	3.23	4.3	1.90
	2.8	1.72			5.6	2.59		
	3.3	1.35						

TABLE XIV.—*Velocities at regular intervals in vertical sections on Housatonic River at Gaylordsville, deduced from data in Table XIII.*

[Velocities in feet per second.]

Depths in parts of total.	Aug. 8.	Oct. 29.	Nov. 13.	Nov. 23.
0.05	2.21	3.00	3.89	3.02
.15	2.23	2.97	3.90	3.01
.25	2.21	2.94	3.91	3.00
.35	2.17	2.90	3.89	2.94
.45	2.10	2.85	3.79	2.85
.55	2.02	2.77	3.60	2.72
.65	1.85	2.57	3.38	2.52
.75	1.66	2.35	3.11	2.34
.85	1.45	2.10	2.79	2.10
.95	1.20	1.75	2.04	1.80
Mean	1.91	2.62	3.43	2.63
.60	1.94	2.67	3.49	2.62

For the purpose of comparison a mean curve for each of the streams has been determined by taking the mean of all the velocities shown in each of Tables II, IV, VI, VIII, X, XII, and XIV. To facilitate comparison, the data for these mean curves have been expressed in percentages of the mean velocity in a vertical section, and are shown in Table XV, the total number of curves being 78. By this arrangement a figure in the column greater than 100 shows a velocity greater than the mean in the vertical section being considered, and a velocity less than 100 shows a velocity less than the mean. The mean curves have been plotted in fig. 2. It will be seen from these curves that the general character of the vertical velocity curves is much the same in each

case, showing fairly conclusively that we may prophesy as to the general character of the vertical velocity curve in natural streams with steep banks and from smooth to moderately rough bottoms, and depths of from 3 to 8 feet. It will be noted that the ratio of the mean velocity to the surface velocity varies from 92 per cent on the Fishkill to 82 per cent on the Catskill, and that the maximum velocity of these streams varies from 13 to 25 per cent greater than the mean, and that at no point do all of the curves fall so closely together as at six-tenths depth. At that point the greatest variation from the mean is 2½ per cent. This shows that the measurements made at six-tenths depth were subject to less variation than those made at any other point, and that in general, on streams of the character here represented, a measurement made at that point would represent approximately the mean velocity in the section. It will be noted that none of the curves cross the line of mean velocity at a greater depth than 0.63, nor at a less depth than 0.56, showing that the point of mean velocity on these streams lies between these two depths.

TABLE XV.—*Averages of velocity curves expressed in terms of mean velocity in a vertical section (represented as 100).*

Stream	Esopus.			Rondout.	Wallkill.	Catskill.	Fishkill.	Tenmile.	Housatonic.	Average of all the streams.
No. of velocity curves.	12.	8.	20.	13.	9.	14.	13.	5.	4.	78.
Bed of stream.	Small gravel.	Bowlders.	Average.	Bowlders.	Silt.	Small gravel and rock ledge.	Large gravel.	Sand.	Gravel.	Various.
Mean depth	6.5.	4.7.	5.8.	6.	7.3.	3.2.	3.7.	5.	4.9.	5.07.
Depth below surface in parts of total:										
0.05	118.6	115.9	117.3	117.9	119.7	124.7	110.7	116.8	114.4	117.0
.15	120.8	116.6	118.8	119.6	118.4	124.8	113.7	115.6	114.3	117.9
.25	118.9	115.5	117.3	118.5	115.4	121.8	113.4	112.7	113.9	116.3
.35	115.0	112.7	113.9	115.9	111.6	116.5	111.3	109.0	112.4	113.2
.45	109.3	109.4	109.3	111.7	107.4	109.7	108.2	104.9	109.5	109.0
.55	102.3	104.8	103.5	105.9	102.5	101.5	104.0	100.4	105.0	103.6
.65	94.4	98.6	96.4	97.2	96.3	92.5	98.3	95.5	97.4	96.5
.75	85.5	89.7	87.5	86.3	89.0	81.9	91.0	89.9	89.3	87.9
.85	74.9	77.8	76.3	72.8	78.6	70.7	81.2	83.3	79.7	77.2
.95	60.3	59.0	59.7	54.2	61.1	55.9	68.2	71.9	64.1	61.4
Mean	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
.60	98.9	101.7	100.2	101.8	99.6	97.2	101.4	98.1	101.2	100.26

In Table XV, under the heading "Average of all the streams," the mean velocity of each depth given in the table is shown, and the curve representing this mean vertical velocity curve is platted in fig. 3 as a solid line. This curve represents the mean of 78 vertical velocity curves, the mean of the vertical velocity curves platted in fig. 2.

It will be noted in this curve that the relation between the mean velocity and the surface velocity is 87; that the maximum velocity is 18 per cent greater than the mean, and that the point of mean velocity is almost exactly at six-tenths depth, the variation, as shown in the last column of Table XV, being about one-fourth of 1 per cent. This shows clearly that a measurement made at six-tenths of the depth of a stream having the general characteristics of those considered will in general represent closely the mean velocity in that section.

To show the relation between the velocity at mid depth and the mean velocity in a vertical section Table XVI has been compiled from Table XV. From this table it will be seen that, upon streams like these being considered, if the mid depth is known, the mean velocity in the vertical section may be found by applying a coefficient of 0.94.

TABLE XVI.—*Relation between velocity at mid depth to mean velocity in a vertical section.*

Stream.	Velocity at mid depth expressed in percentage of the mean.	Coefficient to be applied to velocity at mid depth to obtain mean velocity.
Esopus	106.4	0.94
Rondout	108.8	.92
Wallkill	104.9	.95
Catskill	105.6	.94
Fishkill	106.1	.94
Tenmile	102.6	.97
Housatonic	107.2	.93
Average	106.3	.94

Humphreys's and Abbott's observations on the Mississippi River gave a coefficient of 0.98, while Ellis, on the Connecticut, found 0.94, and Wheeler and Lynch, on the Merrimac flume, found 0.95. It will be seen that there is a variation of 5 per cent on the streams being considered in this paper, and that the results of Humphreys and Abbott on the Mississippi and Ellis on the Connecticut vary from each other by 4 per cent, although the rivers are both large and have somewhat the same characteristics. In view of these facts, it seems that it is somewhat better to measure the velocity at the point of mean velocity than to measure the velocity at mean depth and apply a coefficient.

It is very evident that the character of the bed will affect to some extent the form of the vertical velocity curve. A rough bed would be expected to retard the velocity near the bottom of the stream. None of the streams under investigation may be considered to have extremely rough beds, but by comparison the beds of Rondout Creek

and Housatonic River may be said to be rough, while those of the Wallkill River and Tenmile Creek are smooth at the point of measurement. Part of the bed of the Esopus is rough and part smooth. In order to determine the effect of the variation in the beds on the flow, the results in Table XV have been classified in Table XVII into streams with rough and smooth bottoms, the Rondout, Housatonic, and part of the curves on the Esopus being in the first column, and the Wallkill, Tenmile, and remaining observations on the Esopus in the second. The results shown in these two columns have been plotted in fig. 3.

It will be seen that the rough bed causes a drag at the lower end of the vertical velocity curve, due largely to eddies formed at the bottom of the stream. This retardation of the water near the bed of the stream causes the point of mean velocity in the vertical section to rise, and a measurement of velocity made at 0.60 depth will therefore be too small. With a smooth bed a measurement made at 0.60 depth will, in general, be too large, the filament of mean velocity being nearer the surface. In other words, in making a measurement of mean velocity in a vertical section the meter should, in general, be suspended above 0.60 depth in streams of rough bed and below 0.60 depth in streams of smooth bed. In the rivers here considered the variation of roughness of beds is so small in the different streams that the error in assuming the velocity at 0.60 depth to be the mean velocity in the vertical section would not be great, but in streams of very rough beds the variation would be more marked.

TABLE XVII.—*Relation between velocities in vertical sections with smooth and rough bottoms.*

Depth below surface—in parts of total.	Smooth bottom: Esopus, Wallkill, Tenmile.	Rough bottom: Rondout, Housatonic.
	Velocity in percentage of the mean.	*Velocity in percentage of the mean.*
0.05	118.7	116.2
.15	118.8	117.0
.25	116.2	116.0
.35	112.4	113.8
.45	107.6	110.3
.55	102.0	105.3
.65	95.4	97.7
.75	87.8	88.3
.85	78.1	76.5
.95	63.0	58.9
Mean	100.0	100.0
.60	99.0	101.6

FLOW OF RIVERS UNDER ICE, SMOOTH AND UNBROKEN COVER.

It is frequently desirable to measure the flow of rivers and canals when they are covered with a coating of ice. It is quite clear that the same relations in various parts of the channel do not hold good when the channel is covered with ice as when the surface is open. The friction between the water and the ice retards the surface velocity, and it is possible that in a few cases the river may flow under a head if the ice cake is heavy and held firmly in position. In making measurements of the flow of a river when frozen over, floats can not be used, and in general a current meter is the most serviceable instrument.

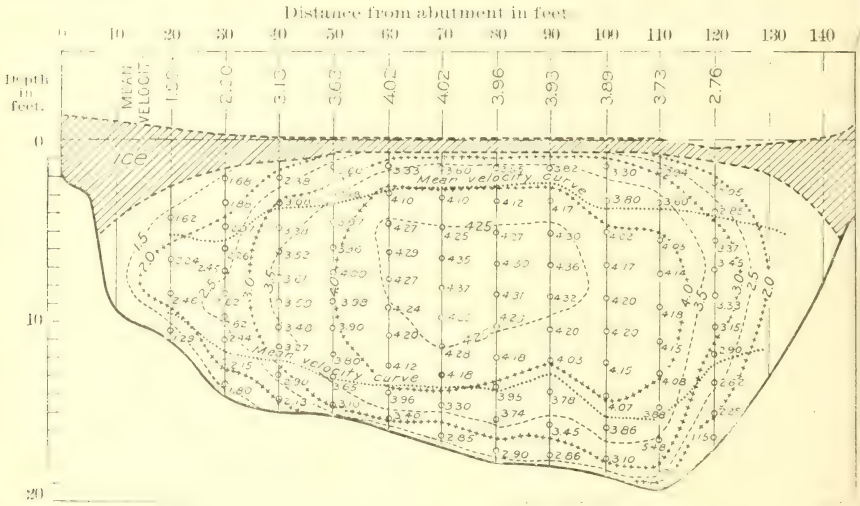


FIG. 4.—Cross section of Wallkill River at New Paltz, showing ice cover and curves of equal velocity in river channel. (Note.—Measurements taken January 23, 1902; 117 measurements of velocity being made with the current meter; mean velocity, 3.23 feet per second; discharge, 6,063 second-feet. The dotted line shows the position of mean velocity in the vertical section.)

During the winter of 1901–2 observations to determine the change of velocity in a vertical plane below the ice were made on Wallkill River, and Esopus, Rondout, and Catskill creeks, and the data collected are presented in the following tables.[a] The observations were made by cutting holes through the ice large enough to admit a current meter. The thickness of the ice in each case is given in the table, and the fact that the water rose in most cases to a point about flush with the surface of the ice shows that there was some pressure upon the flowing stream. It may be of interest in passing to note the distribution of the velocity in the cross section, as shown in fig. 4, the result of the gagings made on the Wallkill River at the New Paltz gaging station, January 23, 1902. The total area of the water section was 1,880 square feet, the mean velocity 3.23, and the discharge 6,063 second-feet. One hundred and seventeen measurements were

[a] These observations were made incidental to the discharge measurements of the streams.

made with the current meter, and the points are platted in the figure, the velocity in feet per second being noted beside each point. The mean velocity in feet per second in a vertical section is shown by the figures across the top of the section. A dotted line showing the position of the mean velocity in the vertical sections has been drawn on the cross section. It will be seen that the maximum velocity occurs near the center of the channel, and at about mid depth, and that the effect of the ice covering is to form a covered flume, the curves of equal velocity being much the same as have been plotted occasionally for such flumes. The water just below the ice is so retarded that there are two points of mean velocity, as shown in figs. 4 and 5.

In the following tables are given the results of measurements made in vertical sections upon the above-mentioned rivers. These measurements were made with a single meter, the velocities being taken at intervals of from 1 to 2 feet, these distances being shown in each case in the table. Tables XVIII, XX, XXII, XXIV, and XXVI show the velocities as determined by actual measurements. At the head of the table are given the date, distance from initial point of sounding, gage height at the time of measurement, total depth of the river (including ice), the thickness of ice, and the depth of water under the ice. In every case the depth, as given in the body of the table, refers to the depth of water under the ice, the lower surface of the ice being considered as zero, and the distances being measured in feet and tenths. Where not otherwise stated, the ice was smooth on the lower side. Some curves were made with ice broken and tilted, but the results were quite different from those obtained with smooth ice, and the results have been given in separate tables (XXIX to XXXIII). The retarding influence of the rough ice was decidedly greater than that of the smooth ice and is so variable that no law can be formulated.

Tables XIX, XXI, XXIII, XXV, and XXVII are derived from the preceding tables by platting the vertical velocity curves, as shown by the original data, and taking from this curve the velocities at regular intervals, one-tenth of the depth apart. The sum of these velocities divided by 10 will give the mean in the section.

In Table XIX, and the others of a similar character, a column has been added, headed "Per cent of mean." The figures of this column are obtained by dividing the corresponding figures in the adjacent column by the mean velocity, which reduces the data for each velocity curve to a similar curve whose mean is 100, and as the depths are then expressed as percentages of total depth, and the velocities as percentages of the mean velocity, the comparison between the curves is facilitated. In all cases for which the data are included within these tables the ice on the surface was smooth both on its upper and lower faces. The few velocity curves taken at times when the ice was broken and tilted are shown in separate tables.

TABLE XVIII.—*Velocities in vertical sections under ice on Wallkill River.*[a]

1901-1902.

Date	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
Point of measurement	85.		75.		53.		40.		50.		80.		90.		100.		40.		50.		60.		70.		80.			
Gage height	11.50.		11.50.		11.50.		11.50.		7.24.		7.24.		7.24.		7.24.		17.33.		17.33.		17.33.		17.33.		17.33.			
Total depth	12.3.		12.2.		9.9.		9.4.		4.6.		6.8.		7.6.		8.8.		15.4.		16.0.		14.8.		16.8.		17.7.			
Thickness of ice	0.7.		0.7.		0.7.		0.4.		1.2.		1.0.		1.0.		1.0.		1.4.		1.0.		0.8.		0.8.		0.7.			
Depth of water	11.6.		11.5.		9.2.		9.0.		3.4.		5.8.		6.6.		7.8.		14.6.		15.0.		14.0.		16.0.		17.0.			
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.		
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*		
	0.8	2.52	0.8	2.43	0.8	2.14	0.3	2.24	0.3	0.80	0.3	0.77	0.3	0.62	0.3	0.87	0.5	2.21	0.5	2.61	0.4	3.23	0.4	3.15	0.3	1.45		
	2.8	3.03	2.8	3.13	2.8	2.68	1.3	2.64	1.3	.95	1.3	1.12	1.3	1.22	1.3	1.15	1.5	3.13	1.4	3.50	1.3	3.91	1.2	3.72	1.0	3.37		
	4.8	3.11	4.8	3.18	4.8	2.68	3.3	2.90	2.3	.85	2.3	1.22	2.3	1.25	2.3	1.25	3.5	3.37	2.2	3.84	2.3	4.19	2.8	4.12	2.6	4.12		
	6.8	2.78	6.8	2.73	6.8	2.71	5.2	2.76	2.8	.67	3.3	1.12	3.3	1.20	3.3	1.27	5.5	3.55	3.8	3.93	4.2	4.30	4.4	4.21	4.2	4.26		
	8.8	2.38	8.8	2.43	8.7	2.12	7.0	2.31	.....	.....	4.3	1.00	4.3	1.05	4.3	1.22	7.5	3.60	5.7	3.93	6.0	4.26	5.8	4.32	5.8	4.28		
	10.8	1.62	11.0	1.65	.....	.....	8.5	1.62	.....	.....	5.3	.77	5.3	.87	5.3	1.15	9.5	3.41	7.6	3.95	7.9	4.23	7.4	4.37	7.4	4.32		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	6.1	.70	6.3	.95	11.5	3.03	8.5	3.97	9.8	4.19	9.0	4.35	9.0	4.30		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	7.3	.70	13.5	1.96	9.3	3.97	11.7	4.12	10.5	4.26	10.5	4.23		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	10.2	3.97	12.6	3.79	12.0	4.21	12.0	4.07		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	11.0	3.95	13.5	3.18	13.6	4.02	13.5	3.88		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.0	3.74	.....	.....	14.2	3.84	15.0	3.60		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	12.8	3.48	.....	.....	14.9	3.03	15.8	3.06		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	13.7	3.01	.....	.....	15.5	2.36	16.5	2.43		
	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	14.5	2.24	.....	.....	.....	.....	.....	.....		

Date	Jan. 23.		Jan. 23.		Jan. 23.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
Point of measurement	90.		100.		110.		40.		70.		80.		90.		100.		80.		90.		90.		80.		40.	
Gage height	17.33.		17.33.		17.33.		9.07.		9.07.		9.07.		9.07.		9.07.		7.78.		7.78.		7.33.		7.33.		7.33.	
Total depth	17.7.		18.8.		19.8.		6.8.		8.8.		8.8.		10.0.		11.5.		7.5.		8.5.		8.0.		7.3.		5.9.	
Thickness of ice	0.7.		0.8.		0.8.		1.0.		1.0.		1.0.		1.0.		1.2.		1.0.		1.0.		2.0.		2.0.		2.4.	
Depth of water	17.0.		18.9.		19.0.		5.8.		7.8.		7.8.		9.0.		10.3.		6.5.		7.5.		6.0.		5.3.		3.5.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Ft.	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*	*Ft.*	*Ft. per sec.*
	0.3	3.23	0.3	2.36	0.7	2.73	0.3	1.32	0.4	1.98	0.3	1.65	0.3	1.70	0.3	1.77	0.3	1.10	0.3	1.15	0.2	0.73	0.3	0.75	0.25	0.42
	1.1	3.88	1.2	3.58	1.7	3.03	1.3	1.65	1.3	2.21	1.3	2.31	1.5	2.33	0.8	2.03	1.0	1.45	1.0	1.52	0.5	.82	.8	.85	0.5	.55
	2.6	4.21	2.2	3.72	3.4	3.55	2.3	1.72	2.3	2.43	2.3	2.45	3.5	2.45	2.8	2.38	3.0	1.65	2.0	1.72	1.5	1.05	1.8	1.00	1.0	.62
	4.2	4.26	4.0	3.93	5.1	4.02	4.3	1.52	4.3	2.29	4.3	2.31	5.5	2.24	4.8	2.47	5.0	1.34	4.0	1.50	2.5	1.02	2.8	.97	1.5	.62
	5.8	4.30	5.7	4.12	6.8	4.12	5.3	1.20	6.3	1.79	6.3	2.00	7.5	1.72	6.8	2.43	6.0	1.10	6.0	1.22	3.5	.92	3.8	.87	2.0	.59
	7.4	4.35	7.4	4.17	8.5	4.17	.....	.....	7.3	1.37	7.3	1.62	8.5	1.37	8.8	2.07	.....	.....	7.0	1.07	4.5	.74	4.8	.62	2.5	.50
	9.0	4.26	9.1	4.21	10.2	4.14	.....	.....	.....	.....	.....	.....	.....	.....	9.8	1.65	.....	.....	.....	.....	5.5	.65	.....	.....	3.0	.42
	10.5	4.09	10.8	4.17	11.9	4.09	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	12.0	3.95	12.5	4.09	13.6	4.00	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	13.5	3.65	14.2	4.05	15.3	3.88	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	14.3	3.53	15.9	3.91	17.0	3.23	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.0	3.01	16.7	3.70	17.3	2.94	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
	16.5	2.52	17.5	2.43	17.7	2.52	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

[a] Bed of river, silt.

TABLE XIX.—*Velocities at regular intervals in vertical sections on Wallkill River, under ice, deduced from data in Table XVIII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 11.		Dec. 11.		Dec. 11.		Dec. 11.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 21.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.		Jan. 23.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	2.47	95	2.35	89	2.02	81	2.22	89	0.75	92	0.77	76	0.70	69	0.90	84	2.38	76	2.60	72	3.33	83	3.60	89	3.55	90
.15	2.81	108	2.81	107	2.32	93	2.53	101	.87	107	1.00	99	1.10	108	1.12	104	3.08	98	3.48	96	4.10	102	4.10	102	4.12	104
.25	3.06	117	3.15	119	2.57	103	2.74	110	.93	114	1.14	113	1.23	121	1.22	113	3.38	107	3.87	107	4.27	106	4.25	106	4.27	107
.35	3.13	120	3.22	122	2.70	109	2.88	115	.95	117	1.20	118	1.25	123	1.27	117	3.52	113	3.96	109	4.29	107	4.35	108	4.30	109
.45	3.07	118	3.12	118	2.74	110	2.89	116	.94	115	1.18	117	1.23	121	1.27	118	3.61	115	4.00	110	4.27	106	4.37	109	4.31	109
.55	2.88	111	2.94	111	2.75	111	2.82	113	.92	113	1.15	114	1.17	115	1.23	114	3.58	114	3.98	109	4.24	105	4.35	108	4.28	108
.65	2.67	102	2.69	102	2.72	110	2.66	107	.87	107	1.08	107	1.06	105	1.16	108	3.48	111	3.90	107	4.20	104	4.28	106	4.18	105
.75	2.41	92	2.42	92	2.60	105	2.42	97	.78	96	.99	98	.94	93	1.05	98	3.27	104	3.80	105	4.12	103	4.18	104	3.99	101
.85	2.06	79	2.06	78	2.38	96	2.15	86	.65	80	.88	87	.82	81	88	82	2.90	93	3.65	100	3.96	99	3.90	97	3.74	94
.95	1.50	58	1.64	62	2.05	82	1.63	66	.48	59	.72	71	.65	64	67	62	2.13	69	3.10	85	3.40	85	2.85	71	2.40	73
Mean	2.61	100	2.64	100	2.48	100	2.49	100	0.81	100	1.01	100	1.01	100	1.08	100	3.13	100	3.63	100	4.02	100	4.02	100	3.96	100

Depth in parts of total.[a]	Jan. 23.		Jan. 23.		Jan. 23.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Jan. 31.		Feb. 10.		Feb. 10.		Feb. 24.		Feb. 24.		Feb. 24.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	3.82	97	3.20	85	2.94	79	1.30	85	1.94	93	1.78	83	1.81	87	1.91	85	1.15	80	1.18	83	0.78	92	0.68	80	0.36	71
.15	4.17	106	3.80	98	3.60	96	1.53	100	2.24	108	2.26	106	2.28	109	2.21	99	1.44	101	1.56	110	.90	106	.87	103	.55	108
.25	4.30	109	4.02	103	4.05	109	1.68	110	2.40	115	2.42	113	2.44	117	2.36	105	1.58	111	1.70	120	1.04	122	.96	114	.61	120
.35	4.36	111	4.17	107	4.14	111	1.73	113	2.44	117	2.44	114	2.46	118	2.45	110	1.65	115	1.72	121	1.03	121	1.00	118	.62	121
.45	4.32	110	4.20	108	4.18	112	1.72	113	2.40	115	2.40	112	2.42	116	2.48	111	1.64	115	1.68	118	.99	116	.99	117	.61	119
.55	4.20	107	4.20	108	4.15	111	1.68	110	2.30	110	2.32	109	2.32	111	2.47	110	1.60	112	1.58	111	.93	109	.96	114	.58	114
.65	4.03	103	4.15	107	4.08	109	1.62	107	2.14	103	2.22	104	2.17	104	2.44	109	1.52	107	1.45	102	.85	100	.90	107	.55	108
.75	3.78	96	4.07	105	3.88	104	1.52	100	1.95	94	2.10	98	1.96	94	2.33	104	1.40	99	1.30	92	.76	90	.83	98	.49	96
.85	3.45	88	3.86	99	3.48	93	1.34	88	1.69	81	1.89	89	1.69	81	2.08	93	1.23	87	1.12	79	.66	78	.71	84	.42	82
.95	2.86	73	3.10	80	2.84	76	1.12	74	1.33	64	1.53	72	1.32	63	1.64	74	1.04	73	.90	64	.56	66	.55	65	.31	61
Mean	3.93	100	3.89	100	3.73	100	1.52	100	2.08	100	2.14	100	2.09	100	2.24	100	1.42	100	1.42	100	0.85	100	0.84	100	0.51	100

[a] The lower surface of the ice is zero depth.

TABLE XX.—*Velocities in vertical sections under ice on Esopus Creek.*[a]

Date	Jan. 9		Feb. 20		Feb. 28		Dec. 4		Dec. 4		Jan. 9		Jan. 9		Feb. 20	
Point of measurement	80.		80.		40.		90.		100.		90.		100.		90.	
Gage heights	6.55.		5.38.		9.14.		5.28.		5.28.		6.55.		6.55.		5.38.	
Total depth	6.8.		5.8.		6.3.		6.85.		5.05.		8.1.		6.1.		6.6.	
Thickness of ice	0.2.		0.1.		0.3.		0.05.		0.05.		0.1.		0.1.		0.2.	
Depth of water	6.6.		5.7.		6.0.		6.8.		5.0.		8.0.		6.0.		6.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.3	1.25	0.3	0.67	0.5	2.56	0.5	0.72	0.5	0.97	0.3	1.10	0.3	0.97	0.2	0.75
	1.3	1.50	1.2	.97	1.5	3.01	1.5	.85	1.5	1.07	1.3	1.35	1.3	1.27	0.9	.97
	2.3	1.52	2.2	.91	2.5	2.99	2.5	1.05	2.5	1.07	2.3	1.40	2.3	1.32	1.9	1.02
	3.3	1.50	3.2	.90	3.5	2.90	3.5	1.10	3.0	1.07	3.3	1.37	3.3	1.30	2.9	.95
	4.3	1.42	4.2	.87	4.5	2.29	4.1	1.09	3.5	1.07	4.3	1.32	4.3	1.25	3.9	.85
	5.3	1.32	5.2	.66	5.5	1.65	4.5	1.00	4.5	.62	5.3	1.17	5.5	1.02	4.9	.72
	6.1	1.10	.....	.....	.....	.....	5.6	.82	.....	.....	6.3	.90	.....	.....	5.9	.57
	.....	.....	.....	.....	.....	.....	6.3	.59	.....	.....	7.5	.60	.....	.....	.....	.....

[a] Bed of river 40 to 80 is bowlders, 90 to 100 silt.

TABLE XXI.—*Velocities at regular intervals in vertical sections on Esopus Creek under ice, deduced from data in Table XX.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Jan. 9.		Feb. 20.		Feb. 28.		Dec. 4.		Dec. 4.		Jan. 9.		Jan. 9.		Feb. 20.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	1.26	91	0.67	81	2.40	93	0.67	75	0.93	98	1.14	99	0.97	81	0.73	88
.15	1.45	105	.85	102	2.75	107	.82	93	1.00	105	1.34	116	1.18	98	.93	112
.25	1.52	109	.94	113	3.00	116	.94	106	1.05	111	1.40	121	1.30	108	.99	119
.35	1.53	110	.95	114	3.08	119	1.03	116	1.07	113	1.40	122	1.33	111	1.01	122
.45	1.51	109	.93	112	3.02	117	1.09	122	1.08	114	1.36	118	1.32	110	.96	115
.55	1.49	107	.91	110	2.88	112	1.10	122	1.08	114	1.30	113	1.30	108	.90	108
.65	1.44	105	.88	106	2.70	105	1.05	118	1.05	111	1.19	103	1.27	106	.83	100
.75	1.37	99	.83	100	2.45	95	.92	102	.96	101	1.03	89	1.23	102	.75	91
.85	1.26	91	.75	91	2.07	80	.77	86	.78	82	.83	72	1.14	95	.66	80
.95	1.02	74	.59	71	1.45	56	.53	60	.50	51	.54	47	.97	81	.54	65
Mean	1.385	100	.83	100	2.58	100	.89	100	.95	100	1.15	100	1.20	100	.83	100

[a] The lower surface of the ice is zero depth.

TABLE XXII.—*Velocities in vertical sections under ice on Rondout Creek.*[a]

Date	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
Point of measurement	80.		90.		80.		90.		92.		92.		80.		40.	
Gage height	6.80.		6.80.		7.00.		7.00.		8.13.		8.43.		8.13.		8.13.	
Total depth	6.2.		6.6.		6.5.		7.0.		7.7.		8.0.		7.9.		6.4.	
Thickness of ice	0.1.		0.2.		0.2.		0.2.		1.5.		1.4.		1.5		1.0.	
Depth of water	6.1.		6.4.		6.3.		6.8.		6.2.		6.6.		6.4.		5.4.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*	*Feet.*	*Feet per sec.*
	0.4	0.62	0.3	0.55	0.8	1.05	0.8	1.07	0.3	0.92	0.3	1.70	0.3	1.40	0.4	1.30
	1.4	73	1.3	.70	1.8	1.32	2.3	1.27	1.5	1.47	1.1	1.91	0.9	1.62	0.9	1.55
	2.4	.77	2.3	.65	2.8	1.47	3.3	1.27	2.5	1.59	2.1	2.00	1.9	1.67	1.9	1.67
	3.4	.71	3.3	.61	3.8	1.40	4.3	1.15	3.5	1.52	3.1	1.98	2.9	1.67	2.9	1.65
	4.5	.62	4.4	.55	4.8	1.35	5.3	1.10	4.6	1.25	4.1	1.73	3.9	1.60	3.9	1.57
	5.6	.51	5.9	.45	5.8	1.07	6.3	1.07	5.7	.82	5.1	1.32	4.9	1.42	4.9	1.32
	------	------	------	------	------	------	------	------	------	------	6.1	.85	5.9	1.15	------	------

[a] Bed of creek is rock, with some bowlders from 0 to 40 and broken rock from 0.5 to 1 foot in diameter the remainder of width.

TABLE XXIII.—*Velocities at regular intervals in vertical sections on Rondout Creek under ice, deduced from data in Table XXII.*

[Velocities in feet per second.]

Depth in parts of total.[a]	Dec. 6.		Dec. 6.		Jan. 14.		Jan. 14.		Feb. 26.		Feb. 26.		Feb. 26.		Feb. 26.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	0.61	93	0.55	95	0.85	69	0.96	84	0.95	74	1.60	98	1.40	93	1.23	81
.15	.68	104	.65	112	1.09	88	1.12	98	1.30	101	1.90	116	1.62	107	1.50	99
.25	.75	114	.68	117	1.27	102	1.23	108	1.52	118	1.98	121	1.67	110	1.62	107
.35	.76	116	.67	116	1.40	113	1.27	112	1.58	122	2.02	123	1.68	111	1.67	111
.45	.75	114	.64	111	1.47	119	1.27	112	1.57	121	2.02	123	1.67	111	1.67	111
.55	.72	110	.61	106	1.46	118	1.25	110	1.53	118	1.87	114	1.64	109	1.65	109
.65	.67	102	.57	99	1.41	113	1.20	105	1.44	112	1.67	102	1.57	104	1.60	106
.75	.62	94	.53	91	1.31	106	1.12	99	1.27	99	1.42	86	1.46	97	1.54	102
.85	.55	84	.48	83	1.18	95	1.04	91	1.03	80	1.13	69	1.32	87	1.42	94
.95	.45	69	.40	70	.96	77	.92	81	.71	55	.79	48	1.07	71	1.20	80
Mean	.66	100	.58	100	1.24	100	1.14	100	1.29	100	1.64	100	1.51	100	1.51	100

[a] The lower surface of the ice is zero depth.

TABLE XXIV.—*Velocities in vertical sections under ice on Catskill Creek.*[a]

Date	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
Station	23.		23.		30.		40.		60.	
Gage height	4.50.		4.96.		4.60.		4.70.		4.80.	
Total depth	4.1.		4.7.		4.5.		5.8.		4.7.	
Thickness of ice	.7.		.5.		1.		1.2.		1.5.	
Depth of water	3.4.		4.2.		3.5.		4.6.		3.2.	
	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.4	1.37	0.3	1.50	0.3	1.42	0.3	2.31	0.3	1.55
	.9	1.57	.7	1.94	.5	1.84	.7	2.41	.7	1.77
	1.4	1.57	1.2	1.96	1.0	2	1.1	2.44	1.2	1.77
	1.9	1.49	1.7	1.89	1.5	2.03	1.0	2.47	1.7	1.61
	2.4	1.16	2.2	1.79	2.0	1.91	2.1	2.44	2.2	1.35
	2.9	1.0	2.7	1.62	2.5	1.74	2.6	2.38	2.7	1.02
	...	...	3.2	1.37	3.0	1.55	3.1	2.31	...	...
	...	...	3.7	1.07	...	...	3.6	2.14	...	...
	...	...	...	...	...	...	4.1	1.89	...	...

[a] Bed of stream rock ledge from 0 to 55, with gravel and silt over remainder of bed.

TABLE XXV.—*Velocities at regular intervals in vertical sections on Catskill Creek under ice, deduced from data in Table XXIV.*

[Velocities in feet per second.]

Depth in feet.	Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.		Feb. 27.	
	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.	Velocity.	Per cent of mean.
0.05	1.24	94	1.45	92	1.21	69	2.30	101	1.38	97
.15	1.42	108	1.82	115	1.85	106	2.42	106	1.68	117
.25	1.55	117	1.95	123	1.98	113	2.46	108	1.76	122
.35	1.60	121	1.91	121	2.04	117	2.47	108	1.78	124
.45	1.56	118	1.86	118	2.03	116	2.44	107	1.71	120
.55	1.48	112	1.75	111	1.95	111	2.40	105	1.58	111
.65	1.34	102	1.60	101	1.85	106	2.32	102	1.43	100
.75	1.19	90	1.42	90	1.72	98	2.20	97	1.22	85
.85	1.01	77	1.19	75	1.55	89	2.04	89	1.01	70
95	.81	61	.85	54	1.32	75	1.75	77	.75	54
Mean	1.32	100	1.58	100	1.75	100	2.28	100	1.43	100

The data contained in Tables XIX and XX have been rearranged and combined in Table XXVI. The mean of the 26 vertical velocity curves taken on the Wallkill is shown in the column headed "Mean." The 26 curves are then separated according to the depth of water under ice at the point whence the observations were taken. In two observations the depth of water was less than 5 feet; in thirteen it was from 5 to 10 feet, and in 11 it was from 10 to 20 feet.

To bring out graphically the form of the vertical velocity curve under ice the data in Table XXVI have been plotted in fig. 5, where the solid line represents the mean of the 26 vertical velocity curves taken in the Walikill. It will be noted that a decided drag occurs at the surface as well as at the bottom of this mean curve; that the maximum velocity occurs at a point about 0.35 of the depth, and that the mean velocity in the vertical occurs at about 0.13 and 0.73 of the depth. There will, in general, always be two points of mean velocity in vertical velocity curves taken under ice.

The results shown in the three last columns in Table XXVI are also plotted in fig. 5, and show the effect of the variation in depth upon the form of the curve. It will be seen that the curves drag more at shallow depths, the curve for depths under 5 feet being more concave than the others, the curve representing the measurements when the water was from 5 to 10 feet in depth being next most concave, while the curve representing the deepest measurement is flattest. This seems reasonable, and would probably hold true in all rivers.

It is frequently desirable to measure the flow of the river when frozen over. This can best be done by taking a large number of point measurements, as represented in fig. 4, but this is a slow process, so that it is important to know at what point the measurement of velocity can be made which will represent the mean velocity in the vertical section.

It will be seen from the four curves in fig. 5 that measurements made at 0.13 and 0.73 of the total depth measured from the bottom of the ice will represent in general the mean velocity in a vertical on a stream with the same general character as the Wallkill. The variation, however, between the curves representing different depths is greater at these two points than at points six hundredths and two-thirds of the depth. At these two points the curves almost coincide. The variation between the various curves was less—in fact within limits only one-half as great—at two-thirds depth as at six-hundredths depth. This shows that in these curves the limit of error is least when measurements are made at two-thirds depth and a coefficient is applied to determine the mean velocity. The mean curve shows a velocity of 105 per cent of the mean at two-thirds depth, so that it would appear that the most accurate method of determining the velocity under ice by observation at one point in the vertical would be to hold the meter at two-thirds depth and apply a coefficient of 0.95 to the observed velocity at that point. This would give a better result than measuring directly the velocity at 0.13 or 0.73 of the depth. In Table XXVII is shown the means of all the curves in the Esopus, Rondout, and Wallkill. These have been plotted in fig. 6. The variation of these three curves is not large, showing that the curve as

plotted represents fairly well the typical velocity curve of rivers of this character under ice cover. In Table XXVIII the results shown in all the preceding tables, for ice cover, including Wallkill, Esopus, Rondout, and Catskill, have been combined according to depth of

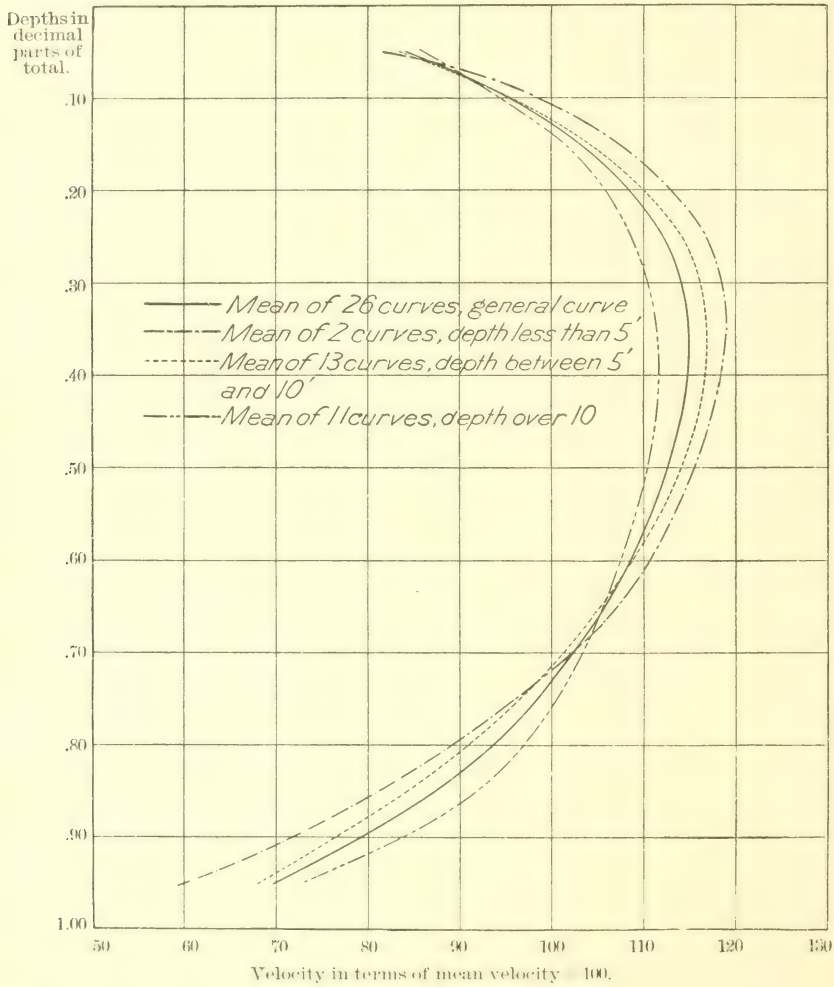


FIG. 5.—Mean vertical velocity curves on Wallkill River, with ice cover, showing the effect upon the curve of variation in depth of water.

NOTE.—The solid line is the mean of 26 vertical velocity curves at all depths; the dot-dash line the mean of two vertical velocity curves at depths less than 5 feet; the dotted line the mean of 13 vertical velocity curves at depths between 5 and 10 feet, and the dash-two-dot lines the mean of 11 vertical velocity curves at depths greater than 10 feet.

water under the ice, and have been plotted in fig. 7, together with the mean of all 47 curves. The form of these curves does not differ materially from those for the Wallkill, plotted in fig. 5. The point at which these curves fall closest together is, however, somewhat higher, at 0.6 depth. To a single measurement made at 0.6 depth a

coefficient of 0.92 should be applied to obtain the mean velocity in the vertical section, while the coefficient 0.95 should be applied to a single measurement made at two-thirds depth, as in the case of the Wallkill, shown in fig. 5.

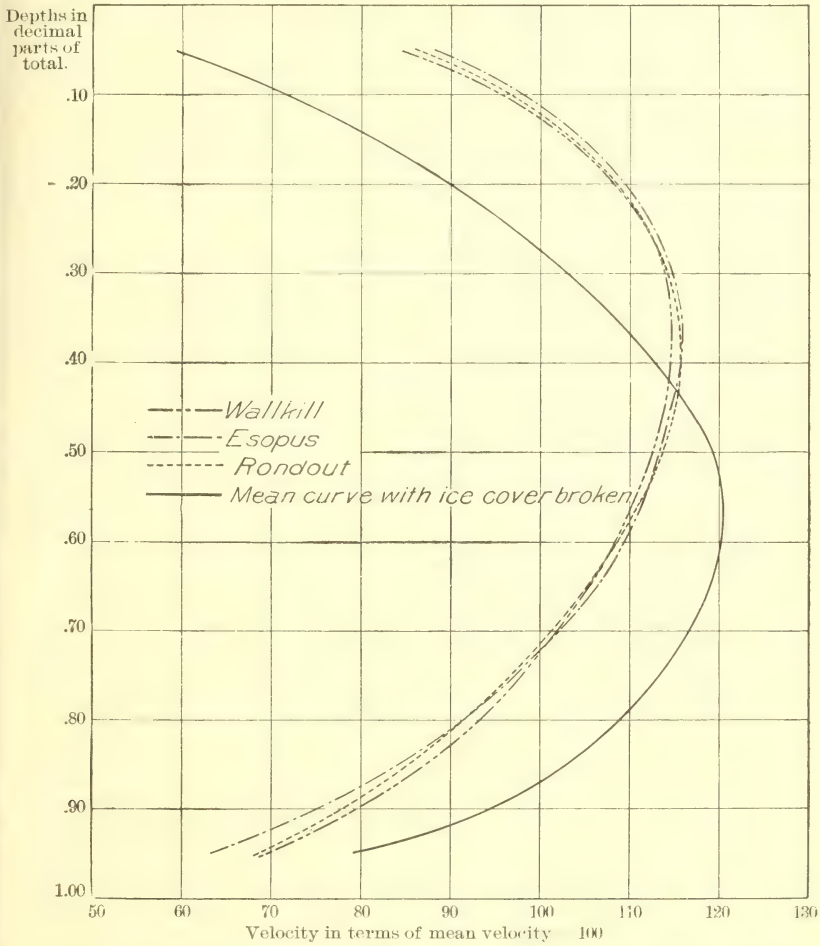


FIG. 6.—Mean vertical velocity curves on Esopus and Rondout creeks and Wallkill River, under ice cover, showing the comparatively slight variation in vertical velocity curves of rivers of this character.

NOTE.—The solid line shows the mean vertical velocity curve on the Wallkill and Rondout with the ice broken and tilted, and shows the decided drag caused by the increased friction at the surface.

There are many engineers who prefer to measure the velocity at mid-depth, and apply a coefficient to obtain the mean velocity in the vertical section. The observations recorded in Table XXVII show that the proper coefficient to apply is 0.88. Observations upon the flow of water under ice cover on the Upper Mississippi were made by

A. O. Powell, assistant engineer, under the direction of Col. Chas. J. Allen, Corps of Engineers, U. S. Army, in 1882 and 1890, and the pub-

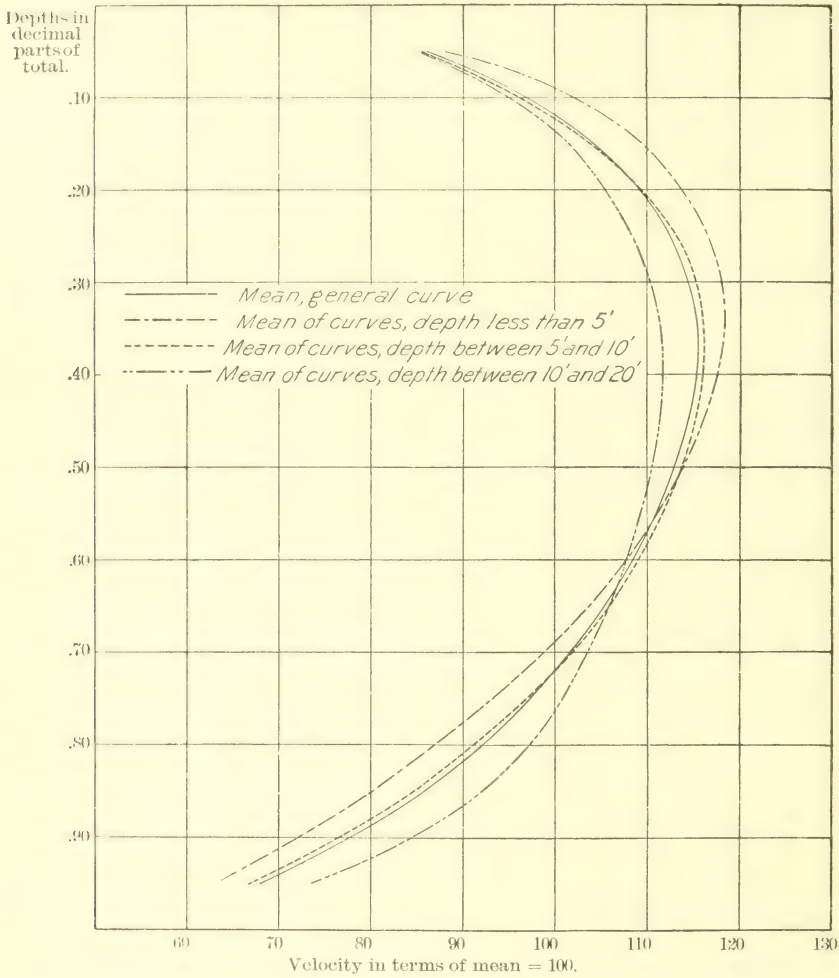


FIG. 7.—Comparison of curves for various depths of water under ice cover with the mean of all curves taken under ice.

NOTE.—The solid line is the mean curve and represents 47 vertical velocity curves. The dash-dot line is the mean of 7 curves with depths of water under ice of less than 5 feet. The dotted line is the mean of 29 vertical velocity curves with depths of water under ice ranging from 5 to 10 feet, and the dash-two-dot line is the mean of 11 vertical velocity curves for a depth of water under ice ranging from 10 to 20 feet.

lished results[a] show that this coefficient varied from 0.87380 to 0.88057.[b]

[a] Ann. Rept. Chief of Engineers, U. S. Army, Part III, 1890.

[b] Owing to the inaccuracies in observations of this kind, it does not seem to the author justifiable to carry the coefficient beyond the second place of decimals. The results obtained in the streams in New York agree with those in the Mississippi to the second place of decimals.

TABLE XXVI.—*Mean vertical velocity curve on Wallkill River and curves separated according to depths of water.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves	26.	2.	13.	11.
		Depth of water under ice.		
Depth below bottom of ice.	Mean.	Less than 5 feet.	Between 5 and 10 feet.	Between 10 and 20 feet.
0.05	84.0	81.5	83.2	85.5
.15	103.0	107.5	103.7	101.5
.25	112.0	117.0	114.0	108.6
.35	114.8	119.0	116.8	111.5
.45	114.0	117.0	115.7	111.4
.55	110.8	113.5	111.8	109.3
.65	105.8	107.5	105.5	105.9
.75	98.4	96.0	96.6	100.9
.85	87.5	81.0	84.5	92.1
.95	69.7	60.0	68.2	73.3
Mean	100.0	100.0	100.0	100.0

TABLE XXVII.—*Mean vertical velocity curves for Esopus, Rondout, and Wallkill, based upon a mean of 100.*

Stream	Esopus.	Rondout.	Wallkill.
Number of velocity curves	8.	8.	26.
Depth below bottom of ice.	Mean.	Mean.	Mean.
0.05	88.2	85.9	84.0
.15	104.7	103.1	103.0
.25	112.9	112.1	112.0
.35	115.9	115.5	114.8
.45	114.6	115.2	114.0
.55	111.8	111.7	110.8
.65	106.8	105.4	105.8
.75	97.4	96.8	98.4
.85	84.6	85.4	87.5
.95	63.1	68.9	69.7
Mean	100.0	100.0	100.0

TABLE XXVIII.—*Mean velocity curves upon Wallkill, Esopus, Rondout, and Catskill for various depths.*

[Velocities given in percentages of mean velocity.]

Number of velocity curves.	7.	29.	11.	47.
	Depth of water under ice.			
Depth below bottom of ice.	Less than 5 feet.	5 to 10 feet.	10 to 20 feet.	Mean of all curves.
0.05	88.0	85.3	85.5	85.8
.15	109.6	103.8	101.5	104.1
.25	116.7	113.2	108.6	112.6
.35	118.4	116.2	111.5	115.5
.45	116.1	115.3	111.4	114.5
.55	111.0	111.8	109.3	111.1
.65	103.7	105.8	105.9	105.5
.75	93.2	96.9	100.9	97.3
.85	80.3	84.8	92.1	85.8
.95	63.0	66.9	73.3	67.8
Mean	100.0	100.0	100.0	100.0

FLOW OF RIVERS UNDER ICE, BROKEN AND TILTED COVER.

A few vertical velocity curves were taken on the Wallkill and Rondout when the ice on the river was broken and more or less tilted. No general law can be determined for such conditions, as the impeding power of the ice varies between wide limits. It is interesting, however, to note in a general way the effect of the ice. The drag at the surface is greatly increased and the curve is changed considerably in form. In Tables XXIX to XXXII will be found the results of the measurements, while in Table XXXIII is the summary of these results. The mean curve, as shown in Table XXXIII, is plotted in fig. 8, together with the mean curves when the ice covering was smooth. It will be seen from this diagram that the point of maximum velocity is 0.55 of the depth, much lower than with smooth ice; that the surface velocity is much less, and that the bottom velocity is greater. This curve would without doubt vary greatly at different times, depending upon the condition of the ice, so that measurement at any point for the determination of the mean velocity would not be advisable. Point measurements at frequent intervals would be necessary in order to obtain reliable results. It is not considered that the results show any decided law of relation between velocities at various depths, but the general form of the curve is characteristic in conditions similar to those under which these were taken.

TABLE XXIX.—*Velocities in vertical section on Wallkill River under ice broken and tilted.*

Date	Dec. 19.		Dec. 19.		Dec. 19.		Dec. 19.		Jan. 23.	
Point of measurement	115.		95.		85.		75.		30.	
Gage height	13.70.		13.70.		13.70.		13.70.		17.33.	
Total depth	18.0.		16.0½.		15.6½.		14.5.		14.4.	
Thickness of ice	4.0.		0.0½.		0.0½.		1.0.		1.4.	
Depth of water.	14.0.		16.0.		15.6.		13.5.		13.0.	
	Depth.	Velocity.	Depth.	Velocity	Depth.	Velocity.	Depth.	Velocity.	Depth.	Velocity.
	Feet.	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*	*Feet.*	*Ft. per sec.*
	0.5	0.30	1.5	2.73	1.1	2.52	1.0	1.52	1.0	1.72
	1.5	1.27	3.5	3.30	3.1	3.08	3.0	2.50	2.5	1.96
	3.5	2.33	5.5	3.48	5.1	3.48	5.0	2.94	4.5	2.26
	5.5	2.71	7.5	3.84	7.1	3.91	7.0	3.03	6.5	2.56
	7.5	2.99	9.5	4.12	9.1	3.95	9.0	3.13	8.5	2.64
	9.5	2.94	11.5	3.93	11.1	3.86	11.0	2.88	10.5	2.24
	11.5	2.64	13.5	3.60	13.1	3.50	13.0	2.45	12.5	1.67
	13.5	1.94	15.5	2.61	15.1	2.64	.....	.....	.....	.....

TABLE XXX.—*Velocities at regular intervals in vertical section on Wallkill River under ice broken and tilted, deduced from Table XXIX.*

Depth in parts of total.	Dec. 19.		Dec. 19.		Dec. 19.		Dec. 19.		Jan. 23.	
	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.05	1.10	45	2.35	68	2.40	71	1.40	54	1.68	77
.15	1.94	80	3.00	86	2.95	87	1.94	74	1.88	86
.25	2.41	99	3.35	97	3.33	98	2.60	99	2.07	94
.35	2.70	111	3.65	105	3.62	106	2.87	109	2.26	103
.45	2.90	119	3.90	112	3.86	113	3.04	115	2.45	111
.55	3.00	123	4.10	118	3.95	116	3.11	118	2.62	119
.65	2.94	120	4.07	117	3.90	115	3.08	117	2.62	119
.75	2.80	115	3.88	112	3.76	111	2.98	113	2.44	111
.85	2.55	104	3.60	103	3.42	101	2.78	106	2.15	98
.95	2.05	84	2.85	82	2.80	82	2.50	95	1.80	82
Mean	2.44	100	3.48	100	3.40	100	2.63	100	2.20	100

TABLE XXXI.—*Velocities in vertical sections on Rondout Creek at Rosendale under ice broken and tilted.*

Date	Dec. 6.		Jan. 14.		Jan. 14.		Jan. 14.	
Point of measurement	50.		40.		50.		60.	
Gage height	6.80.		7.00.		7.00.		7.00.	
Total depth	5.6.		4.8.		6.4.		6.4.	
Thickness of ice	0.2.		0.8.		0.4.		0.4.	
Depth of water	5.4.		4.0.		6.0.		6.0.	
	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.	Depth.	Velocity in feet per second.
	0.3	0.21	0.5	0.35	0.5	0.72	0.5	0.55
	1.3	.54	1.5	.75	1.5	.82	1.5	.87
	2.8	.55	2.5	.97	2.5	.90	2.5	1.17
	3.8	.57	3.5	.85	3.5	.90	3.5	1.15
	4.9	36			4.5	.87	4.5	1.10
					5.5	.72	5.5	.85

TABLE XXXII.—*Velocities at regular intervals in vertical section on Rondout Creek under ice broken and tilted, deduced from Table XXXI.*

Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.	Velocity in feet per second.	Per cent of mean.
0.25	53	0.24	34	0.67	81	0.48	51
.46	99	.40	57	.76	92	.68	72
.54	115	.55	79	.82	100	.87	93
.57	122	.70	100	.88	107	1.06	112
57	122	.85	121	.90	110	1.19	127
56	120	.95	136	.91	111	1.19	126
55	117	.97	139	90	109	1.14	121
50	107	.95	135	.88	107	1.06	113
43	92	.88	126	.82	100	.96	102
.25	53	.51	73	.69	83	78	83
.468	100	.70	100	.823	100	.941	100

TABLE XXXIII.—*Summary of curves on Wallkill and Rondout, under ice broken and tilted.*

Stream	Wallkill.	Rondout.	
Number of velocity curves	5.	4.	9.
Depth of water below bottom of ice.	13 to 16 ft. River bed: Silt.	4 to 6 ft. River bed: Bowlders and gravel.	Mean.
0.05	63.0	54.8	59.3
.15	82.6	80.0	81.4
.25	97.4	96.8	97.1
.35	106.8	110.2	108.3
.45	114.0	120.0	116.7
.55	118.8	123.2	120.8
.65	117.6	121.5	119.3
.75	112.4	115.5	113.8
.85	102.4	105.0	103.6
.95	85.0	73.0	79.7
Mean	100.0	100.0	100.0

QUALITY OF RIVER WATER.

A study of the turbidity, color, alkalinity, and hardness of these streams has been made in conjunction with the discharge measurements. It is thought that the information derived from such determinations will be of value to engineers investigating the future supply of New York City.

TURBIDITY AND COLOR.

Water in its ideal condition is perfectly clear and limpid, and has a slightly blue color. Filtered water, distilled water, and many spring waters approach closely to the ideal water. Most river waters are, however, either colored by contact with peat, muck, or decaying vegetation, or are turbid by reason of mud or silt carried in suspension. Muddy waters are often spoken of as colored waters, and in a sense this is correct where the mud consists of clays or other materials having distinct colors, but for convenience of classification it is better to refer to such waters as turbid waters, and to limit the term "colored waters" to those containing in solution vegetable matters which color them.

It has been observed that highly colored waters are usually free from turbidity, and vice versa, this being due to the fact that colored waters usually flow from drainage areas underlain by hard rocks not easily disintegrated, or from regions where the soils are firm or sandy, and especially from swamps. On such areas there is but little material that would be washed from the river banks and held in suspension, while the coloring material is present in the greatest abundance. In many parts of the United States shales or other soft materials

form the underlying beds. These readily disintegrate and form clay soils that are readily washed by hard rains. Waters from such areas are usually turbid and very highly colored.

Turbidity and color are principally important in their effect upon the appearance of water, whereas the other impurities discussed in this paper have absolutely no effect upon the appearance, and can be found only by their chemical action.

TURBIDITY.

The turbidity of water is a subject of great importance to the sanitary engineer. In questions of water supply, turbidity is often the important feature in the selection of a source of town supply; the number of days upon which the turbidity is above a certain fixed standard is also important, in that it may determine the size of reservoir required to store clear water sufficient to tide over the time of greatest turbidity, or for the sedimentation of suspended matters in the reservoir water. The importance of this subject varies with the part of the country studied, the waters in the New England States and New York being comparatively clear, while in the Southern Atlantic States and in the Ohio and Mississippi valleys high turbidities are the rule.

In the Northeast the terms "very slight, "slight," "distinct," and "decided" have been used by analysts to express the amount of suspended matter present. These degrees of turbidity have been estimated by the appearance of the sample to the eye when viewed toward the light. As the importance of these analyses has been more appreciated, particularly in connection with the purification of waters and the extended studies upon waters of high turbidity, it has been found that a more definite scale was necessary in order that proper comparisons of waters from various sources might be made.

In the filtration of water the engineer desires to know the amount of coagulant necessary to properly clarify the water, and it has been found that the turbidity gives a reliable index of the quantity of coagulant required. The object of the more recent studies has been, therefore, to express it numerically on some scale, referred to some standard, which can be easily reproduced and will be permanent.

There has been considerable difference of opinion as to the proper standard for turbidity comparisons, and some confusion has resulted. It is important that any standard selected should be applicable to both field and laboratory practice, and that observations made by different methods should be readily comparable.

The United States Geological Survey has had occasion, from time to time, to make observations of turbidity of rivers of which discharge measurements were made. Realizing the importance of a uniform standard for turbidity, the Survey has cooperated with Mr. Allen

Hazen and Mr. George C. Whipple in order that such a standard might be adopted. Mr. Hazen and Mr. Whipple have made joint investigations and studies, and have recommended the standard given below. This will be used in the future by the Survey, and it is hoped may be adopted generally throughout the United States.

PROPOSED TURBIDITY STANDARD.[a]

The standard of turbidity shall be a water which contains 100 parts of silica per million in such a state of fineness that a bright platinum wire 1 millimeter in diameter can just be seen when the center of the wire is 100 millimeters below the surface of the water and the eye of the observer is 1.2 meters above the wire, the observation being made in the middle of the day, in the open air, but not in sunlight, and in a vessel so large that the sides do not shut out the light so as to influence the results. The turbidity of such water shall be 100.

The turbidity of waters more turbid than the standard shall be computed as follows: The ratio of the turbidity of the water to 100 shall be as the extended volume is to the original volume, when the water is diluted with a clear water until the mixture is of standard turbidity.

The turbidities of waters lower than the standard should be computed as follows: The ratio of the turbidity of the water to 100 shall be as the ratio of the original volume of water of standard turbidity is to the extended volume when such water is diluted with a clear water until its turbidity is equal to that of the water under examination.

This standard can be used in both field and laboratory. In the field the wire method will be carried out as at present, except for a new graduation, while in the laboratory the methods of dilution and comparison now in use for the silicia standard will be used.

METHOD OF APPLICATION TO THE PLATINUM-WIRE PROCESS.

A rod with a platinum wire inserted in it at a fixed point and projecting from it at a right angle will be used as at present. The graduation shall be as follows: The graduation mark of 100 shall be placed on the head at a distance of 100 millimeters from the center of the wire. Other graduations will be made, based on the best obtainable data, in such a way that when a water is diluted the readings will decrease in the same proportion as the percentage of the original water in the mixture. Such a rod, having the graduation shown in the table below, shall be known as the United States Geological Survey turbidity rod of 1902. When this rod is immersed in water the visibility of the projecting platinum wire at the depth from the surface shown in the second column will determine the degree of turbidity, as indicated in the first column.

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[a] From a letter signed by Messrs. Allen Hazen and George C. Whipple.

Graduation of rod.

Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.	Turbidity.	Depth of wire.	Corresponding value on reciprocal scale.
	Mm.			*Mm.*	
7	1095	0.023	70	138.0	0.184
8	971	.026	75	130.0	.196
9	873	.029	80	122.0	.208
10	794	.032	85	116.0	.219
11	729	.035	90	110.0	.230
12	674	.038	95	105.0	.242
13	627	.041	100	100.0	.254
14	587	.043	110	93.0	.273
15	551	.046	120	86.0	.295
16	520	.049	130	81.0	.314
17	493	.052	140	76.0	.334
18	468	.054	150	72.0	.35
19	446	.057	160	68.7	.37
20	426	.060	180	62.4	.41
22	391	.065	200	57.4	.44
24	361	.070	250	49.1	.52
26	336	.076	300	43.2	.59
28	314	.081	350	38.8	.65
30	296	.086	400	35.4	.72
35	257	.099	500	30.9	.82
40	228	.111	600	27.7	.92
45	205	.124	800	23.4	1.09
50	187	.136	1000	20.9	1.21
55	171	.148	1500	17.1	1.49
60	158	.160	2000	14.8	1.72
65	147	.172	3000	12.1	2.10

This table is compiled from observations made at Cincinnati, St. Louis, New Orleans, Pittsburg, Brooklyn, Philadelphia, and Boston, for records of which we are indebted to several observers. The values of the turbidities by the reciprocal scale are included in the table as a matter of convenience, but they do not form a part of the standard.

This graduation is subject to revision whenever additional data shall make it necessary, and revised rods shall be designated by the same name, but with the year of revision substituted for 1902. The revisions shall have as their basis the one hundred mark, 100 millimeters from the wire.

Near the end of the rod, at a distance of 1.2 meters from the platinum wire, a wire ring shall be placed directly above the wire, through

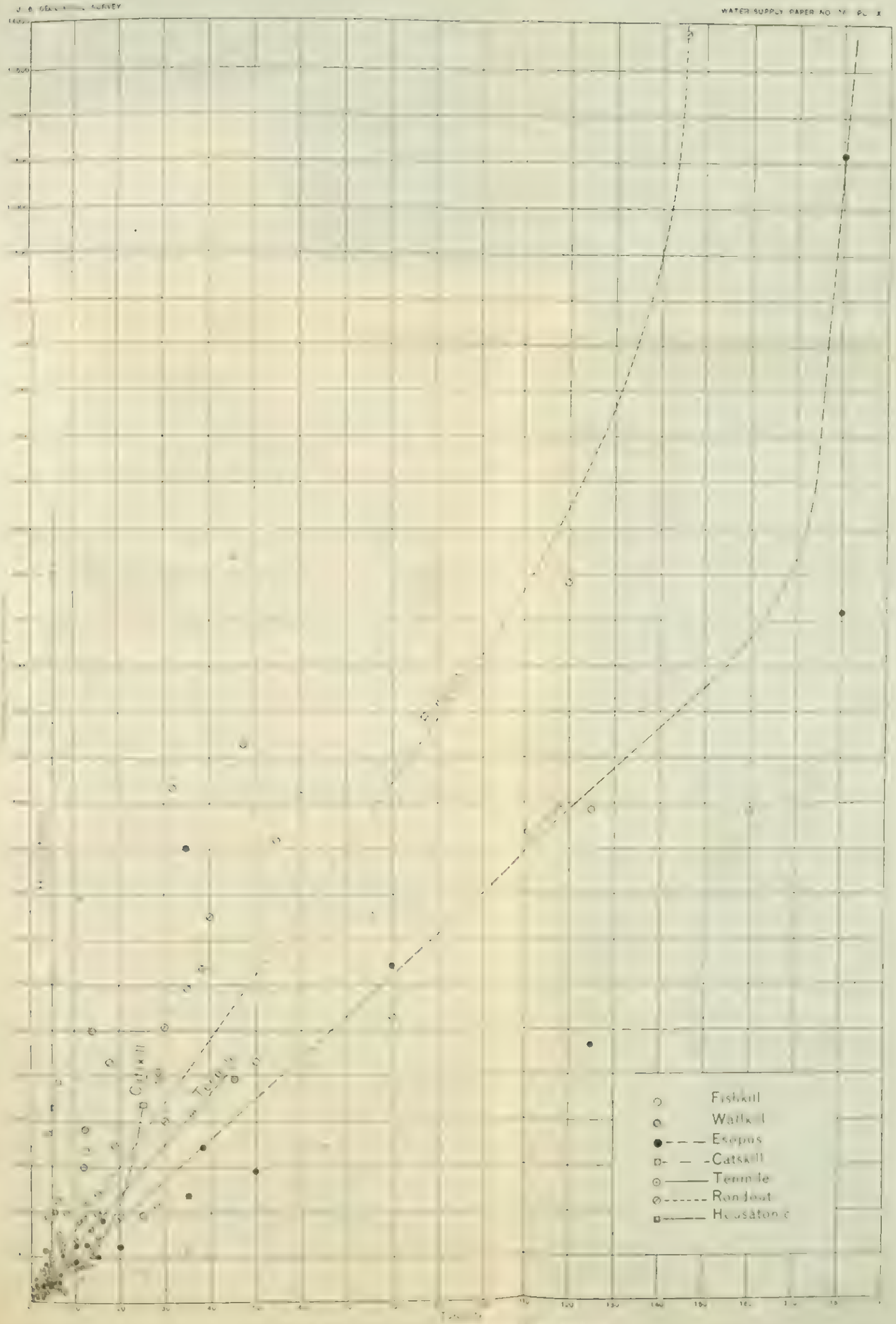


DIAGRAM SHOWING RELATION OF TEMPERATURE OBSERVATIONS

which the observer will look, the object of the ring being to control the distance from the wire to the eye.

When the turbidity is greater than 500 the water should be diluted before the observation is made. When the turbidity is below 7 this method can not be used, and comparison should be made with the silica standard properly diluted in bottles or tubes.[a]

The number obtained by dividing the weight of suspended matter in parts per million by the turbidity as obtained above shall be called the coefficient of fineness. If greater than unity, it indicates that the matter in suspension in the water is coarser than the standard; if less than unity, that it is finer than the standard.

This standard is proposed with the idea of combining the best features of the platinum-wire and silica methods of measuring turbidities as commonly used, and of avoiding, as far as possible, the objections to each.

The wire method is most convenient as a field method. With the reciprocal scale, which until now has been used, it is open to the serious objection that the readings are not proportional to the amount of turbidity-producing matter in the water.

The silica standard is free from this objection and is more convenient as a laboratory method, but is not well adapted to field use, and is open to the objection that it is possible that the value may be changed by variations in the fineness of the silica particles composing the standard.

The standard now proposed is intended to overcome the above-mentioned defect in the platinum-wire method with the reciprocal scale, and at the same time to put a control on the value of the silica standard. Applying it in one way or the other, it is adapted to both field and laboratory use, and the results obtained should check substantially.

METHOD OF MAKING OBSERVATIONS.

The method of making the observations by means of the platinum wire is as follows: Take a stick of wood about 5 feet long and five-eighths of an inch square, more or less, and insert a platinum wire at a point about 1 inch from the end, so that the wire will be at right angles to the stick and project at least 1 inch. The wire should be 0.04 inch or 1 millimeter in diameter; the stick is then graduated, the lines for the various turbidities being at distances from the wire shown in the table on page 2.

Observations of turbidity are taken by putting this stick into the water under examination as far as the wire can be seen; the turbidity is then read from the scale. This is most conveniently accomplished by having a second or smaller stick placed in front of the first, the end of which is brought to the water line when the wire can just be

[a] Described by Whipple and Jackson in Technology Quarterly, Vol. XII, No. 4, December, 1899.

seen. Upon removing the two together the position of the smaller stick on the scale gives the turbidity.

Observations are to be taken in all cases in open air, as too high results are obtained under a roof, even with very good light; and they should preferably be taken in the middle of the day and not in direct sunlight. In case the sun is shining the observer can stand so that his shadow covers the water immediately about the stick and wire. The observations are taken with the eye of the observer at the ring before mentioned, 1.2 meters from the wire, although some variation in this does not materially influence the result. The wire should be kept bright and clean. In case it is lost, a clean bright pin can be used until another wire can be obtained. When the surface of the water in the stream is agitated by currents, waves, etc., or in case the depth is not sufficient to give the required immersion, or if for any reason observations can not be well taken from the bank, a pail or tub may be filled with water and the turbidity observations taken in it. In many cases this procedure is preferable to measurement in a stream, but the observation must be taken immediately upon filling the vessel. The diameter of the vessel should be equal to at least twice the depth at which the wire is immersed, as otherwise the results of the reading will be affected.

When the turbidity of the water is above 500, that is, in case the wire can be seen through less than 1 inch of water, the results obtained by direct measurement are not accurate. Such water should be diluted by 1, 2, or 4 volumes of clear water in the pail or tub, and thoroughly mixed.

The turbidity is taken as above described, and multiplied by the ratio that the total volume of water bears to the water in the mixture. Clear water can be obtained from a well or any other source obviously clear, or nearly so.

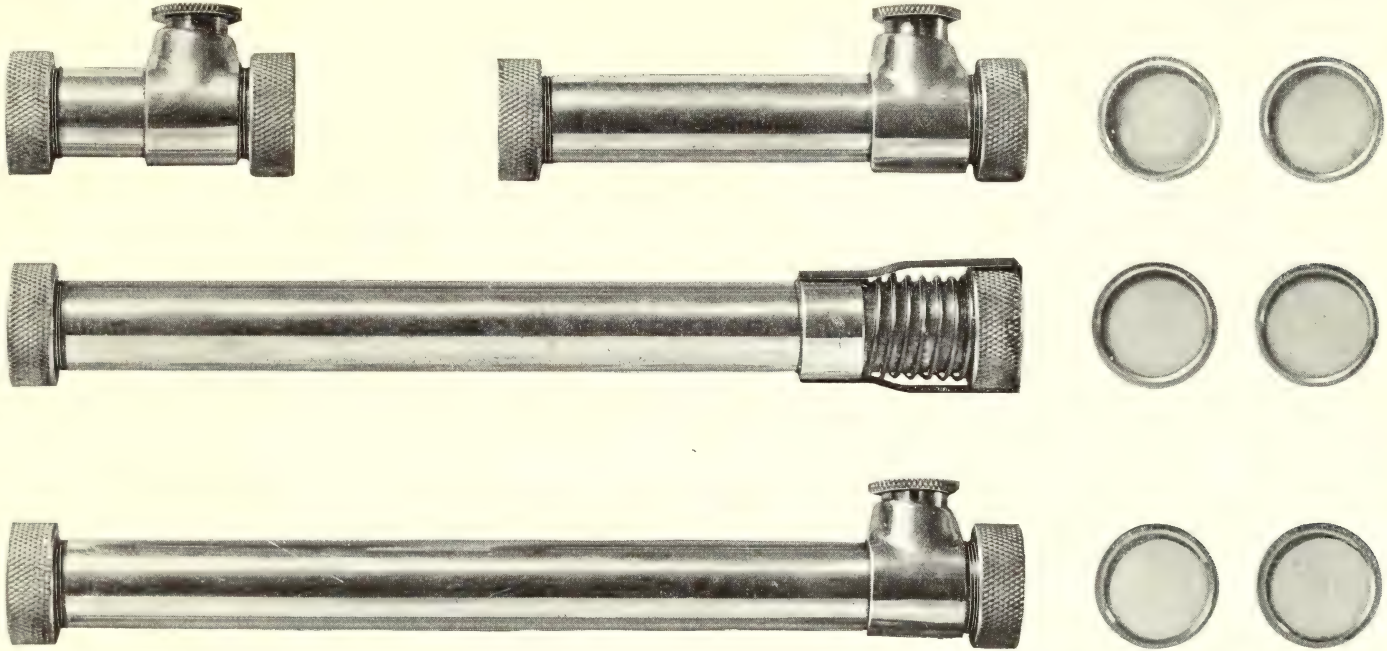
The statement of turbidity in such cases should contain memoranda that the observations were taken in this way, and should give the amount of dilution.

If waters have a turbidity less than 7 direct reading can not be used, and indirect methods must be resorted to.

The "wire method" has been described first in this paper, as it is best suited to field work. Besides this method, there are two others that have commended themselves to practical use. First, the use of standards of comparison; second, the diaphanometer.[a]

In the determinations of turbidity of waters in rivers considered in this paper, the turbidities were in general too low for accurate measurements by the wire method, and as the samples had to be shipped to the laboratory for other determinations, the turbidity was found by comparison with standards. These standards were made up from dia-

[a] These are both laboratory methods, and have been described by Mr. George C. Whipple and Daniel D. Jackson, in the Technology Quarterly, Vol. XII, No. 4, December, 1899.



TUBES AND DISKS FOR MEASURING IN THE FIELD THE COLOR OF RIVER WATER.

tomaceous earth thoroughly washed and ignited to remove the organic matter. The earth is then washed in hydrochloric acid and rinsed with water, after which it is pulverized. One-half grain is added to 500 c. c. of distilled water and thoroughly agitated. This stock mixture contains 1 grain of pure silica per liter, or 1,000 parts per 1,000,000, and when well shaken will always give the same turbidity, which is called a standard 1,000. For waters of low turbidities, like those found in New York State, standards are made by diluting the stock mixture with distilled water in measured proportions and comparing the collected samples with the various standards in gallon bottles, while with higher turbidities smaller quantities of the standards are placed in 100 c. c. Nessler tubes, with which the samples in like tubes are compared. This is a laboratory method, and is more precise than the wire method of making determination of turbidity, but requires that samples be collected and shipped to the laboratory.

In order that some idea of the meaning of the various standards may be obtained, the following table is inserted:

Table showing meaning of various numbers on silica scale.

Silica standard.	Destriptive term.
0	None.
1-2	Very slight.
2-5	Slight.
5-20	Distinct.
Above 20	Decided.

COLOR.

The platinum-cobalt method of measuring color, as devised by Allen Hazen, is generally considered the standard.

A standard solution which has a color of 500 shall be made by dissolving 1.246 grams potassium-platinic chloride[a] ($PtCl_4,2KCl$), containing 0.5 gram platinum, and 1 gram of crystallized cobalt chloride ($CoCl_2,6H_2O$), containing 0.25 gram of cobalt in water, with 100 cubic centimeters concentrated hydrochloric acid, and making up to 1 liter with distilled water. By diluting this solution standards shall be prepared having values of 0, 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, and 70. The numbers correspond to the metallic platinum in the solutions in parts per million. These shall be kept in 100-cubic-centimeter Nessler jars of such diameter that the liquid shall have a depth between 20 and 25 centimeters and shall be protected from dust. The

[a] Potassium-platinous chloride is a salt that is often substituted by dealers in place of the potassium-platinic chloride. It is sometimes incorrectly labeled. The platinous salt has a reddish color, while the platinic salt has a yellow color.

color of a sample shall be observed by filling a similar tube with water and comparing it with the standards. The observation shall be made by looking vertically downward through the tubes upon a white surface placed at such an angle that light is reflected upward through the column of liquid. The reading shall be recorded to the nearest unit. Waters that have a color darker than 70 shall be diluted before making the comparison, in order that no difficulties may be encountered in matching the hues. Water containing matter in suspension shall be filtered until no visible turbidity remains. If the suspended matter is coarse, filter paper may be used for this purpose; if the suspended matter is fine, the use of the Berkfeld filter is recommended, but it must be thoroughly washed each time before using. The use of a Pasteur filter is to be avoided, as it exerts a decolorizing action.

The determinations of color upon the streams considered in this paper, and given on the following pages, were made by the above laboratory method. For the sake of completeness, however, the field method of making determinations of color will be described.

It is impracticable to carry the standard tubes above described into the field for observations, and yet field observations are of great convenience and value to the sanitary engineer, and in general to the investigations of the United States Geological Survey.

Standard disks of colored glass have been prepared by Mr. Allen Hazen, in cooperation with the Survey, as standards for measuring color of water in the field (Pl. X). These disks have been rated by Mr. George C. Whipple to correspond with the platinum-cobalt standard. The color is measured by balancing the color of the water in a metallic tube with glass ends against the colors of glass disks of known value. The number on each disk represents the corresponding color of a water. This is not a new standard, but a new application of an old standard. The glass disks are rated to correspond with the platinum-cobalt color standard. The process bears the same relation to the usual laboratory process that an aneroid barometer bears to a mercurial barometer. The metallic tubes and glass standards are more portable and better adapted to field use than the Nessler tubes and color solutions previously used.

Color standards.—The standards are disks of amber-colored glass, mounted with aluminum. Each disk carries two numbers. One number is over 100, and is a serial number for the purpose of identification. The other number is less than 100, and shows the color value of the disks; that is to say, the color of each disk is equal to the color of a solution of the designated number of parts per million of platinum with the required amount of cobalt to match the hue when seen in a depth of 200 millimeters.

Each apparatus has a series of glass disks of varying values, so that waters within a reasonable range can be matched by them. When a water comes between two disks its value can be estimated

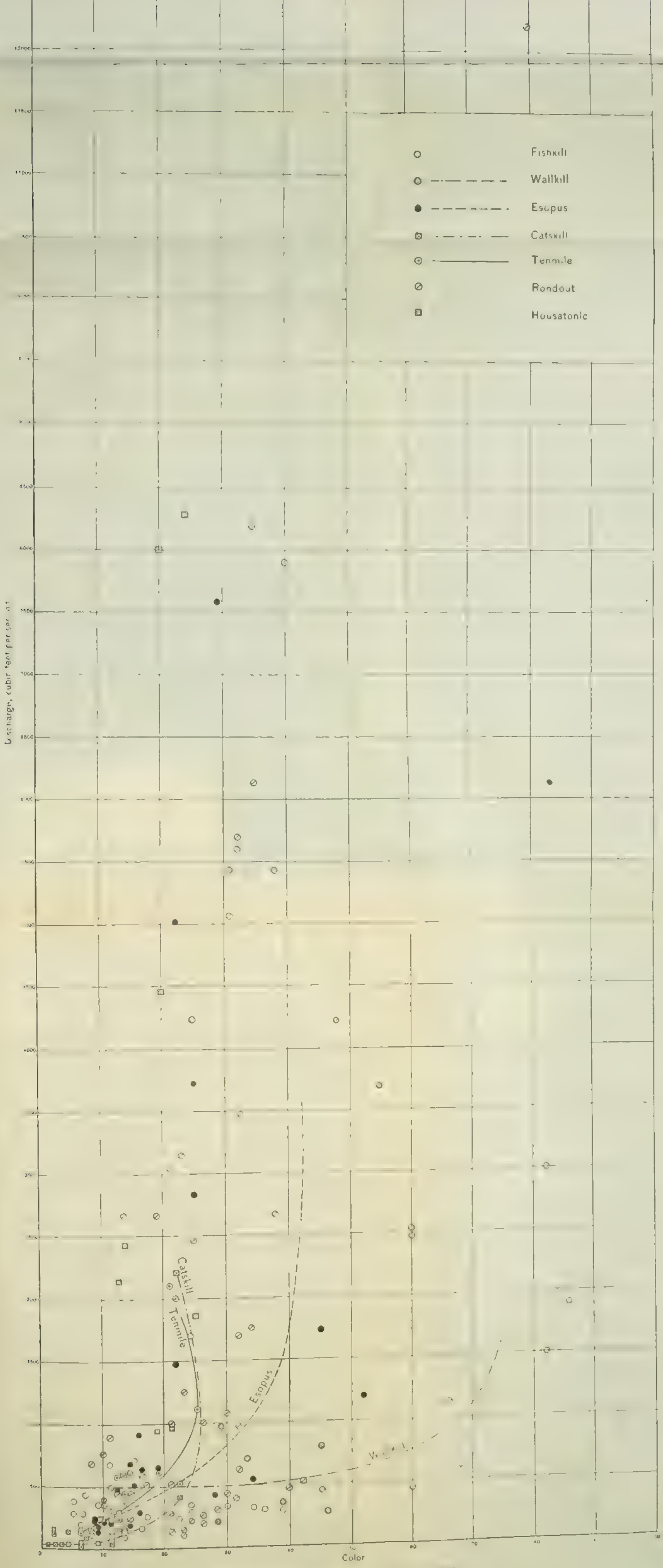


DIAGRAM SHOWING RESULTS OF COLOR OBSERVATIONS

between them by judgment. Two or more disks can be used, one behind the other, in which case their combined value is the sum of the individual values. By combining the disks of a series in different ways a considerable number of values can be produced, allowing the closer matching of many waters.

Filling the tubes.—The tube, having an aluminum stopper, is to be filled with water, the color of which is to be determined. Rinse the tube once or twice by filling and emptying it. The second tube, having the clips to hold the glass disks, is made much like the one holding the water to facilitate comparison. Theoretically this tube should be filled with distilled water. Practically it makes very little difference whether it is filled with distilled water or empty. Use distilled water when it is convenient to do so, and when distilled water of unquestionable quality is at hand; otherwise wipe the inside of the tube dry to prevent fogging of the glass ends, and proceed with the tube empty.

Holding the tubes.—Hold the tubes at such a distance from the eye that the sides of the tubes just can not be seen. This occurs when the near end of the tube is 8 or 9 inches from the eye. Hold the tubes at such an angle that both can be seen at once with one eye. Good results can not be obtained in any other way. Let the tubes change places once or twice, as sometimes the light on the right and left is not quite equal.

Background.—There should be a clear white background with a strong illumination. The best results can not be obtained with either too little or too much light. In a gray day look at the sky near the horizon and away from the sun. In a bright day look at a piece of white paper or tile, upon which a strong light falls. The white surface may be vertical and the tubes held horizontally, or the tubes may be held at an angle directed downward toward a horizontal surface, as may be most convenient. Good results can not be obtained by artificial light.

Turbid water.—The colors of very turbid waters can not be measured in this way. Slight turbidities do not interfere seriously with the results. Waters too turbid for direct observations should be filtered through thick filter paper before being tested, and in case the turbid matter is fine and in large amount even this method may fail. The turbidity of water should be taken as far as possible in connection with color observations, except in cases where it is obvious from inspection that there is practically no turbidity.

Highly colored waters.—Some waters will be found having a higher color than can be matched by the standards. In general, waters with colors above 100 should not be matched in 200-millimeter tubes, and the results with waters having colors below 80 will be considerably more accurate than with more highly colored ones. Two procedures are possible with waters having higher colors—namely, to dilute with dis-

tilled water before measuring the color or to use shorter tubes. The latter procedure is the more convenient, but both are equally accurate. To measure the color with short tubes, put the highly colored water in a tube of one-half the usual length and match as usual. It is not necessary to have a short standard holder. The 200-millimeter tube can be used. After the water is matched the result is multiplied by 2. In case the color is too high to be read in a 100-millimeter tube it can be put in a 50-millimeter tube, and the result multiplied by 4. When dilution is used the highly colored water is mixed with one or more volumes of distilled water, the color matched, and the result multiplied by a corresponding factor. The tube itself can be used for measuring the colored water and the distilled water, and the mixing can be done in a tumbler or any convenient clean vessel.

Cleaning the tubes.—The tubes should always be kept clean and the glass ends protected. All the ends are removable for the purpose of cleaning, and should not be screwed on too tightly. They should be water-tight when only screwed up loosely, and if screwed on hard they may stick so as to come off with difficulty.

ALKALINITY.

The alkalinity of water is practically a measure of the carbonates and bicarbonates present. The determination is made as follows: Put 100 c. c. of the sample into a 6-inch porcelain evaporating dish. Add two or three drops of a 0.1 per cent aqueous solution of methyl-orange. If the water is alkaline, this will impart to it a faint yellowish brown color. Then from a burette graduated in tenths of a cubic centimeter run in a fiftieth-normal solution of sulphuric acid until the color of the water changes to a faint pink. The acid must be added in small portions (only one drop at a time as the end point is reached) and the water stirred with a glass rod after each addition. The number of cubic centimeters of fiftieth-normal acid required, when multiplied by ten, gives the alkalinity of the water expressed in equivalent parts per million of calcium carbonate. That is, if 1.8 c. c. is required to cause the color of the indicator to change from brown to red, then the alkalinity of the water is 18 parts per million. Inasmuch as it is necessary to add a certain amount of fiftieth-normal acid to 100 c. c. of water which has no alkalinity in order to produce the typical color change, the reading obtained must be corrected for this amount. This correction for the indicator varies with different individuals, but it seldom exceeds 0.3 c. c.

Other indicators, such as lacmoid or erythrosine, may be used in place of methyl-orange, and in certain instances their use is to be preferred, but for general field work methyl-orange is most convenient.

PERMANENT HARDNESS.

The Clark's soap method has been used in the examinations of river waters given in the following tables. This method gives reliable

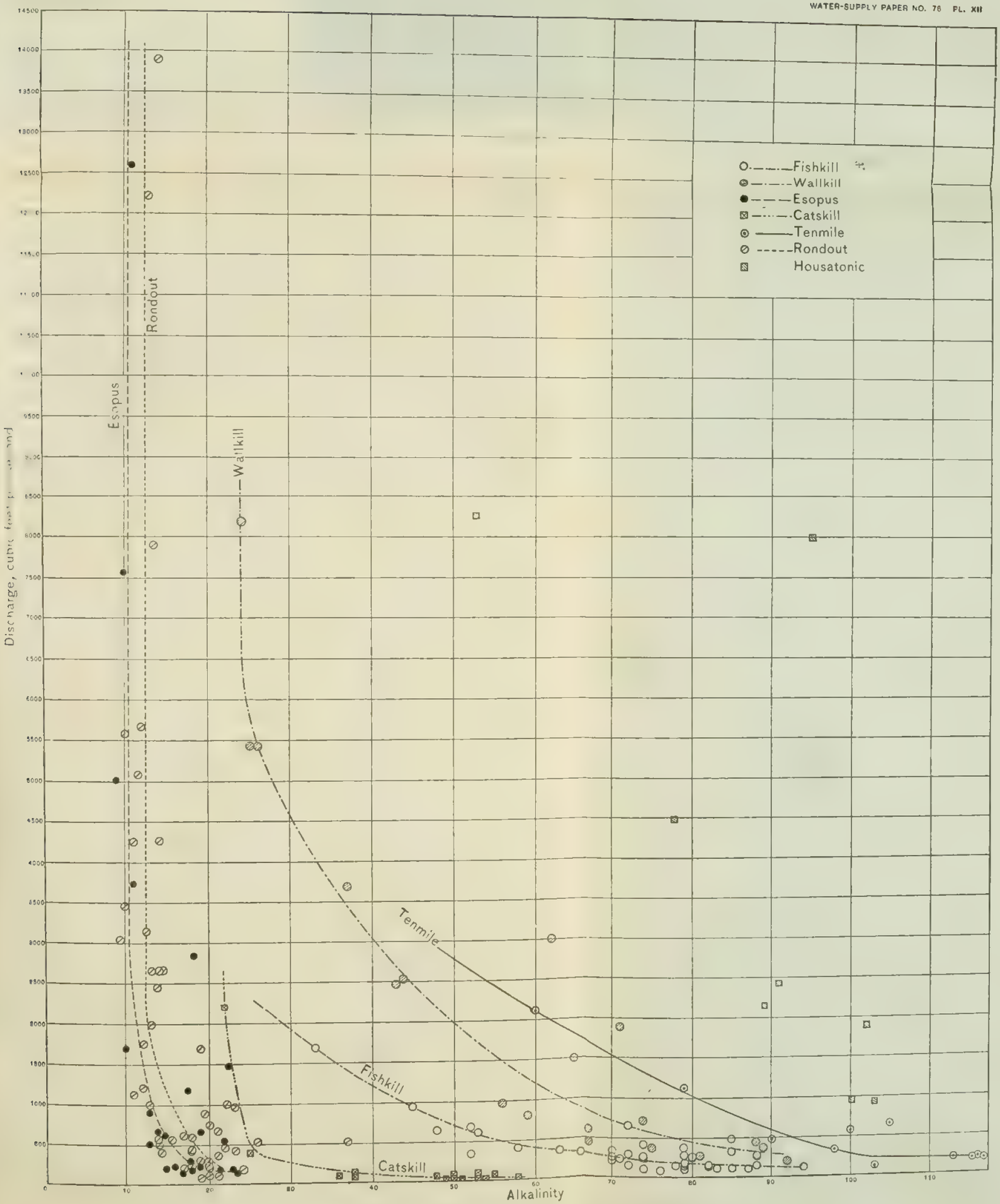


DIAGRAM SHOWING RESULTS OF ALKALINITY OBSERVATIONS.

results for waters as soft as those under consideration, but for the hard waters of the Central States Hehner's acid method will perhaps give more reliable and uniform results.

Results of determinations of hardness obtained by various observers are frequently very discrepant, and it is not uncommon to have results reported by chemists which are worthless on account of faulty methods. It is hoped that the determinations of hardness may be made upon a more uniform basis throughout the country, so that the results may be comparable.

In the following tables are given the results of the observations upon turbidity, color, alkalinity, and hardness, together with the discharge of Esopus, Rondout, Wallkill, Catskill, Fishkill, Tenmile, and Housatonic:

Turbidity color, alkalinity, and hardness of streams.

CATSKILL CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 19	[a]2.62	6	1	58.0		28
Aug. 27	[a]2.95	11	2	48.0		77
Sept. 2	[a]3.00	7	2	53.0		89
Sept. 8	[a]2.90	9	2	55.0		66
Sept. 23	2.73	2	2	54.0		39
Oct. 4	2.70	4	1	51.0		36
Oct. 10	2.65	1		53.0	53.0	31
Oct. 22	2.82	6	3	50.0		51
Nov. 8	2.70	1		49.0	50.0	36
Nov. 19	2.75	3	1	50.0	50.0	42
Dec. 9	3.30	2		38.0	44.5	110
1902.						
Jan. 15	3.50	2	1	38.0	42.0	144
Feb. 27	4.90	22	11	25.0	26.0	400
Apr. 10	6.70	22	25	22.0	24.0	2,200
May 10	3.47	4	6	36.0	42.0	133
June 3	2.82	6	1	42.0	50.0	99
June 24	2.70	9	3	47.0	51.5	43
July 9	3.40	9	2	45.0	47.0	113
July 23	6.11	35	25	35.0	44.5	1,602
Aug. 2	5.36	33	12	42.0	49.0	1,005
Aug. 13	3.49	12	1	50.0	50.5	135
Aug. 27	2.74	11	4	56.0	52.0	394
Sept. 5	2.79	6	4	56.0	56.0	50

[a] Taken from gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 28	7.15	42	4	37.0		620
Sept. 1	7.62	32	20	23.0		980
Sept. 3	7.80	66	6	11.0		1,126
Sept. 4	7.13	68	15	18.0		602
Sept. 19	6.87	30	12	18.0		430
Do	6.87	30	13	14.0		430
Oct. 11	6.50	26	4	17.0		185
Oct. 3	6.95	40	4	22.0	22.0	481
Oct. 15	7.65	26	8	22.0	[a] 21.0	1,601
Oct. 22	6.70	28	3	20.0	[a] 19.0	314
Oct. 31	6.50	24	4	24.0	[a] 24.0	185
Nov. 13	7.00	21	14	26.0	27.0	515
Nov. 16	6.60	26	5	20.0	26.0	249
Nov. 19	6.40	21	2	20.0	24.0	123
Nov. 22	6.35	23	3	19.0	25.0	92
Nov. 26	7.30	32	7	17.0	23.0	728
Nov. 29	6.80	31	3	21.0	24.0	380
Dec. 3	6.40	23	7	21.0	24.5	123
Dec. 6	6.80	21	3	19.0	23.5	280
Dec. 10	9.80	32	65	19.0	25.0	1,700
Dec. 11	9.50	38	([b])	13.0	20.0	2,650
Dec. 12	8.50	34	19	12.0	17.5	1,750
Dec. 15	16.70	80	([b])	13.0	18.0	12,230
Dec. 16	11.00	48	75	11.0	20.0	4,250
Dec. 25	7.25	13	7	14.0	26.0	592
Dec. 30	12.20	32	60	10.0	20.0	5,574
1902.						
Jan. 7	7.00	17	5	14.0	24.0	515
Jan. 14	6.70	14	4	20.0	23.5	240
Jan. 18	6.70	14	3	18.0	21.0	240
Jan. 23	10.30	32	3	10.0	12.5	3,480
Jan. 25	7.90	23	1	12.0	14.5	1,212
Jan. 28	7.70	80	10	21.0	25.5	675
Feb. 4	9.50	14	18	14.5	21.5	2,650
Feb. 11	8.20	11	11	19.5	24.5	900
Feb. 14	7.85	10	6	20.0	24.5	742
Feb. 27	10.45	22	30	13.0	15.9	2,000

[a] Likely too low. [b] Bottle broken

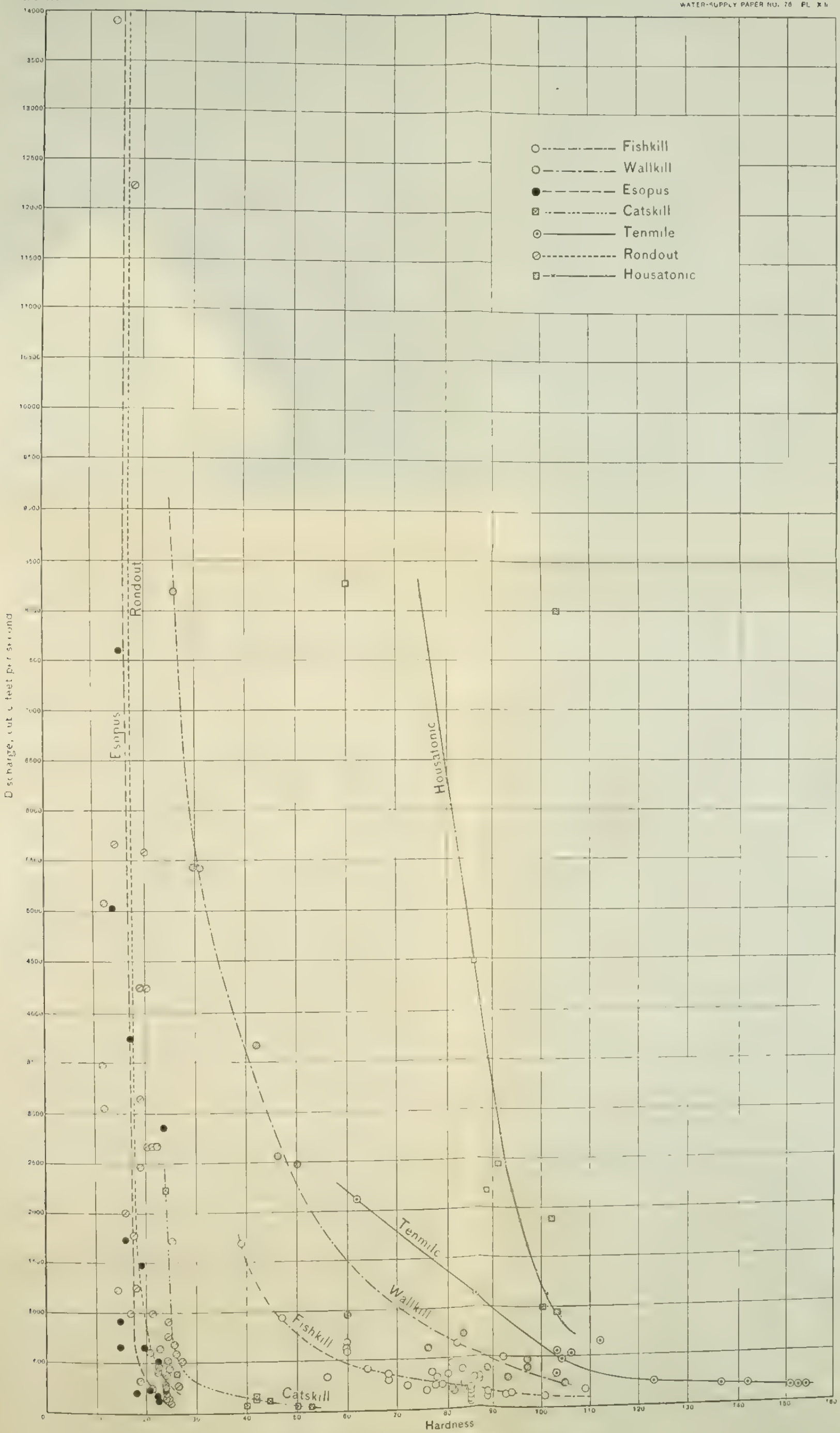


DIAGRAM SHOWING RESULTS OF HARDNESS OBSERVATIONS.

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Mar. 1	17.55	42	145	14.0	14.3	13,900
Mar. 2	14.00	40	120	14.5	13.5	7,900
Mar. 3	11.75	31	55	11.0	11.9	5,075
Mar. 4	9.90	21	30	9.5	12.0	3,043
Mar. 8	7.75	30	28	14.0	16.5	1,084
Mar. 9	12.70	35	48	12.5	15.0	6,120
Mar. 9	9.50	19	50	14.0	21.0	2,650
Mar. 10	10.00	23	80	12.5	19.5	3,150
Mar. 29	11.00	25	40	14.0	19.0	4,250
Apr. 8	7.65	21	15	13.0	17.0	1,000
Apr. 19	11.95	32	32	12.0	14.0	5,665
Apr. 24	6.90	14	4	18.0	22.0	447
Apr. 26	7.10	16	35	15.5	20.5	585
Apr. 30	9.30	25	28	13.5	19.0	2,470
May 26	6.90	12	8	23.0	24.5	447
May 28	7.10	14	21	23.0	24.5	585
June 5	6.45	14	18	27.0	28.0	156
June 6	6.40	13	7	23.0	25.0	163
June 18	6.50	13	10	28.0	30.0	185
June 19	6.30	13	14	32.0	32.5	75
June 22	7.20	12	20	25.0	31.2	656
June 28	7.55	21	24	20.5	24.7	920
July 3	6.80	31	30	21.5	22.8	380
July 19	6.30	15	2	27.0	30.5	75
July 21	8.65	40	95	21.0	22.0	1,885
July 22	9.75	35	105	15.0	19.5	2,890
July 23	8.60	45	35	13.0	17.0	1,840
July 26	9.85	45	45	15.0	24.0	2,991
July 31	7.35	30	14	14.0	24.0	765
Aug. 7	7.39	28	8	19.0	26.0	838
Aug. 13	6.80	17	2	18.0	22.0	380
Aug. 15	6.50	16	1	22.0	22.5	185
Aug. 20	6.40	20	2	24.0	28.0	123
Aug. 21	6.35	16	2	25.0	27.0	92
Aug. 25	6.25	11	5	23.0	24.5	60
Aug. 27	6.30	14	13	30.0	29.0	75
Aug. 30	6.35	12	5	26.0	27.5	92
Sept. 5	6.10	11	4	26.0	31.0	35

Turbidity, color, alkalinity, and hardness of streams—Continued.

RONDOUT CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Sept. 8	6.20	11	2	28.0	31.0	50
Sept. 11	6.50	14	6	23.0	24.5	185
Sept. 16	6.30	17	3	23.0	26.0	75
Sept. 17	6.20	17	3	23.0	28.0	50

ESOPUS CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 25	7.67	52	35	17.5	(a)	1,200
Aug. 27	6.02	34	7	22.0		540
Aug. 29	5.72	28	3			430
Sept. 4	6.27	19	13	19.0		640
Sept. 21	4.78	11	3	23.0		198
Sept. 26	4.55	9	4	23.5		167
Oct. 3	5.25	16	6	18.0		295
Oct. 8	4.70	14	3	18.0		188
Oct. 17	6.30	14	10	14.0	15.0	650
Nov. 1	4.75	9	4	15.0	18.0	195
Nov. 14	4.75	9	4	21.0	22.0	195
Nov. 18	4.45	9	2	17.0	22.0	153
Dec. 4	5.30	10	6	16.0	20.5	223
Dec. 11	[b] 11.40	45	38	10.0	16.0	1,721
Dec. 19	8.35	22	50	22.5	19.0	1,470
Dec. 30	12.10	25	80	11.0	17.0	3,723
1902.						
Jan. 9	6.50	15	15	13.0	21.0	514
Jan. 22	16.00	29	180	10.0	15.0	7,600
Feb. 7	6.80	16	20	15.0	19.5	628
Feb. 20	5.35	8	5	19.0	23.5	231
Mar. 1	20.40	48	180	11.0	16.5	12,600
Mar. 12	9.90	25	125	18.5	23.5	2,843
Apr. 10	13.25	22	35	9.0	13.5	5,021
Apr. 23	6.94	16	21	13.0	15.0	910
May 14	5.83	12	10	16.0	20.0	474
May 24	5.02	8	4	19.0	24.0	238
June 5	5.03	14	17	20.0	22.5	2,345
June 16	4.48	10	5	24.0	26.0	1,358
June 26	5.00	18	13	20.0	22.0	2,312

[a] From Aug. 25 to Oct. 8, hardness not determined.

[b] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

ESOPUS CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
July 9	5.80	20	12	16.0	27.5	4,504
July 16	5.13	10	10	18.0	27.5	2,688
July 24	8.11	35	15	15.0	28.5	1,348
July 30	7.65	23	8	14.0	24.0	1,155
Aug. 12	6.28	21	8	24.0	26.5	550
Aug. 21	4.94	14	6	23.0	25.5	191
Sept. 4	4.49	11	6	34.0	31.0	133

WALLKILL RIVER.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 17	6.75	78	3	77.0		565
Aug. 20	7.2	110	9	48.5		794
Aug. 23	6.25	104	6	58.0		321
Aug. 24	6.05	110	12	64.0		232
Aug. 28	5.85	82	14	62.0		165
Aug. 31	5.95	86	12	71.0		196
Sept. 5	8.55	82	12	65.0		1,503
Sept. 19	7.30	45	13	59.0		814
Oct. 9	6.50	60	7	67.0		440
Oct. 31	6.10	46	5	81.0	93.0	264
Nov. 9	5.94	28	4	92.0	105.0	202
Nov. 16	6.50	45	9	88.0	97.0	440
Dec. 11	[a] 11.50	60	45	43.0	50.0	2,480
Dec. 19	13.70	55	38	37.0	42.0	3,680
Dec. 30	20.20	35	45	24.0	26.0	8,190
1902.						
Jan. 13	8.05	33	15	74.0	83.0	717
Jan. 23	16.40	38	125	25.0	30.0	5,422
Feb. 10	7.78	21	14	67.0	76.0	596
Feb. 24	7.30	19	10	89.0	97.2	382
Mar. 10	16.40	31	160	26.0	31.0	5,422
Apr. 21	7.55	29	25	56.0	60.0	977
May 1	10.00	60	28	44.0	46.0	2,540
May 21	6.33	39	8	75.0	89.0	356
June 6	6.40	20	13	73.0	84.0	381
July 17	5.70	33	5	82.0	90.0	126
July 29	7.49	52	23	54.0	72.0	942

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

WALLKILL RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
Aug. 6	7.98	68	25	62.0	71.0	1,150
Aug. 15	6.72	48	8	83.0	84.0	518
Aug. 28	5.86	24	5	88.0	89.0	169
Sept. 6	5.78	38	5	57.0	61.0	145

TENMILE RIVER.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Sept. 12	5.90	13	2	121.0	.....	364
Oct. 26	5.00	12	4	134.0	142.0	166
Nov. 11	4.75	8	2	146.0	151.0	120
Nov. 22	4.80	8	2	147.0	154.0	129
Dec. 2	4.75	6	1	137.0	152.5	120
Dec. 17	8.41	25	12	79.0	86.0	1,120
Dec. 27	6.54	22	9	103.0	106.0	524
1902.						
Jan. 10	5.75	11	4	98.0	103.0	328
Feb. 4	6.30	13	11	90.0	104.0	460
Feb. 13	5.00	8	6	126.0	137.0	166
Mar. 3	[a] 10.41	21	36	60.0	61.1	[b] 2,100
Apr. 7	[a] 6.18	12	3	100.0	103.0	558
May 2	6.46	19	7	105.0	112.0	640
May 15	4.88	12	1	118.0	123.0	230
June 9	4.44	16	15	130.0	139.0	122
June 30	4.90	19	6	133.0	160.0	249
July 21	7.20	40	25	88.0	90.0	821
Aug. 4	4.69	11	3	129.0	141.0	1,848
Aug. 19	4.28	10	4	138.0	160.0	100
Sept. 2	3.95	10	4	139.0	155.0	63

FISHKILL CREEK.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Aug. 21	[c] 4.45	39.0	2	88	.....	286
Aug. 31	[c] 4.57	24.0	4	85	.....	335
Sept. 4	[c] 4.42	24.0	6	88	.....	277
Oct. 8	3.90	13.0	3	82	93.0	113

[a] All readings on this and following dates made on new gage placed 0.33 foot higher than the old gage.

[b] Approximate.

[c] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1901.						
Oct. 10	3.85	11.0	2	94	100.0	100
Oct. 17	4.50	36.0	4	72	[a]68.0	305
Oct. 25	4.05	16.0	2	88	[a]84.0	154
Oct. 31	4.00	12.0	3	87	89.0	140
Nov. 5	3.90	12.0	5	85	89.0	113
Nov. 8	3.95	11.0	4	85	92.0	500
Nov. 13	4.35	17.0	4	80	87.0	250
Nov. 15	4.05	21.0	4	78	109.0	154
Nov. 19	3.95	13.0	4	79	94.0	126
Nov. 23	3.90	8.0	4	83	89.0	113
Nov. 26	4.30	22.0	5	74	84.0	233
Dec. 17	6.10	29.0	12	45	47.0	926
Dec. 19	5.10	21.0	7	58	64.0	409
Dec. 24	4.55	11.0	5	71	78.0	224
Dec. 26	4.55	13.0	4	74	79.0	224
Dec. 31	7.30	24.0	12	33	39.0	1,682
1902.						
Jan. 2	5.65	15.0	7	52	60.0	673
Jan. 7	4.80	12.0	3	66	78.0	300
Jan. 9	4.65	11.0	2	70	81.0	[b]253
Jan. 14	5.00	5.0	3	79	83.0	[b]370
Jan. 16	4.35	6.0	5	79	85.0	[b]172
Jan. 21	4.15	6.0	3	82	85.0	[b]128
Jan. 28	4.90	30.0	25	52	55.5	[b]334
Jan. 30	4.95	9.0	4	63	77.0	[b]352
Feb. 4	5.50	13.0	7	53	60.0	[b]594
Feb. 7	5.20	11.0	6	72	82.0	640
Feb. 11	4.80	7.0	4	74	81.0	430
Feb. 18	4.40	5.0	6	80	86.0	268
Feb. 20	4.40	7.0	11	79	87.0	268
Mar. 7	5.20	11.0	14	48	60.0	640
Apr. 18	4.60	10.0	5	63	68.0	345
Apr. 22	4.30	9.5	4	70	72.0	233
Apr. 24	4.10	11.0	3	72	76.0	169
Apr. 29	4.00	13.0	3	79	82.0	140
May 15	3.90	11.0	4	74	85.0	113
May 20	3.80	11.0	3	76	85.0	88
May 22	3.70	13.0	2	79	85.0	66

[a] Likely too low. [b] Taken from daily gage height record.

Turbidity, color, alkalinity, and hardness of streams—Continued.

FISHKILL CREEK—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
May 28	4.55	34.0	5	70	80.0	405
June 6	3.50	11.0	3	79	81.0	115
June 10	3.80	19.0	4	79	85.0	175
June 16	3.50	14.0	5	84	90.0	115
June 19	3.50	16.0	5	86	91.0	115
July 5	3.60	15.0	4	81	90.0	135
July 8	3.50	20.0	2	83	85.0	115
July 11	3.40	14.0	3	86	86.0	95
July 16	3.10	10.0	2	89	94.0	55
Aug. 4	3.60	13.0	2	81	86.0	135
Aug. 6	3.40	11.0	3	82	89.0	95
Aug. 11	3.60	14.0	12	74	81.0	135
Aug. 13	3.60	17.0	2	74	81.0	135
Aug. 19	3.20	10.0	3	84	90.0	65
Aug. 21	3.10	7.0	2	84	86.0	55
Sept. 1	2.90	12.0	4	94	96.0	35
Sept. 2	2.80	12.0	5	93	96.0	30
Sept. 5	2.90	8.0	3	89	97.0	35
Sept. 9	3.00	9.0	3	85	89.0	40
Sept. 12	3.05	12.0	3	73	85.0	45
Sept. 15	3.20	12.0	2	77	87.0	65

HOUSATONIC RIVER.

1901.						
Oct. 29	4.05	19.0	3	103	103.0	935
Nov. 13	4.83	25.0	4	102	106.0	1,860
Nov. 23	4.10	21.0	5	100	105.0	980
Dec. 28	5.16	14.0	6	91	97.0	2,420
1902.						
Jan. 11	5.00	13.0	5	89	92.0	2,145
Feb. 14	[a] 8.30	20.0	5	96	103.0	8,000
Mar. 18	7.63	24.0	.....	53	60.0	8,277
May 3	6.10	20.0	11	78	86.0	4,459
June 22	4.70	24.0	4	89	92.0	1,530
June 23	4.50	18.0	3	92	94.0	1,177
June 25	4.30	14.0	3	93	95.0	1,070

[a] Backwater.

Turbidity, color, alkalinity, and hardness of streams—Continued.

HOUSATONIC RIVER—Continued.

Date.	Gage height.	Color.	Turbidity.	Alkalinity.	Hardness.	Discharge in second-feet.
1902.						
June 26	4.30	15.0	2	94	95.0	1,070
July 2	4.60	18.0	3	90	90.0	1,400
July 4	4.70	20.0	6	91	93.0	1,530
July 6	4.50	16.0	2	93	93.0	1,177
July 8	5.00	22.0	3	91	94.0	2,145
July 15	3.90	14.0	5	85	101.0	750
July 18	3.90	18.0	7	95	98.0	750
July 22	6.70	34.0	22	63	75.0	5,119
July 25	5.60	30.0	12	73	82.0	3,050
July 29	4.90	26.0	7	88	91.0	1,800
Aug. 1	4.80	35.0	4	88	94.0	1,650
Aug. 5	4.20	14.0	4	102	109.0	983
Aug. 8	4.50	14.0	2	102	107.0	1,177
Aug. 12	5.20	32.0	5	73	83.0	2,300
Aug. 15	4.50	31.0	3	85	86.0	1,177
Aug. 19	3.70	11.0	3	96	106.0	...
Aug. 22	3.90	11.0	2	96	99.0	750
Aug. 26	3.90	11.0	4	103	107.0	750
Aug. 29	3.90	10.0	3	96	104.0	750
Sept. 2	3.60	10.0	2	98	113.0	640
Sept. 5	3.60	9.0	1	104	110.0	640
Sept. 9	3.40	10.0	1	105	109.0	490
Sept. 12	3.90	13.0	2	97	104.0	750

Though the number of observations is not sufficient to give accurate curves, the results as shown in the tables have been plotted in Pls. IX, XI, XII, and XIII[a] and tentative curves drawn showing the relation of these qualities to the discharge of the stream. In the curves representing alkalinity and hardness the relation seems to be well marked. The diagrams show the relative hardness of the various streams, also ratio of decrease in hardness as the discharge increases. The regularity of the points enables one to prophesy with fair precision the alkalinity or hardness that might be expected at intermediate discharges. The turbidity and color are, as might be expected, far more irregular. It would not be expected that during a rapidly rising flood we should find the same turbidity as at the time of general high water. The

[a] Since the diagrams were plotted many more observations have been obtained and are included in these tables. The diagrams have not been changed, as they are only intended to be suggestive.

effect, too, of a local shower on one tributary may affect the quality of the water much more than the same increase of water from another tributary, so that in an exhaustive study of a large river the effect of floods on each tributary is important, and should be studied rather than the river as a whole. Most of the tributaries of the streams under consideration are short, and storms would usually cover a large part of the drainage basin.

It is not considered that results have been obtained that are final upon these points, so that their publication is in the nature of a progress report. Measurements are being continued, and it is hoped that better curves can be constructed later. The curves representing tur-

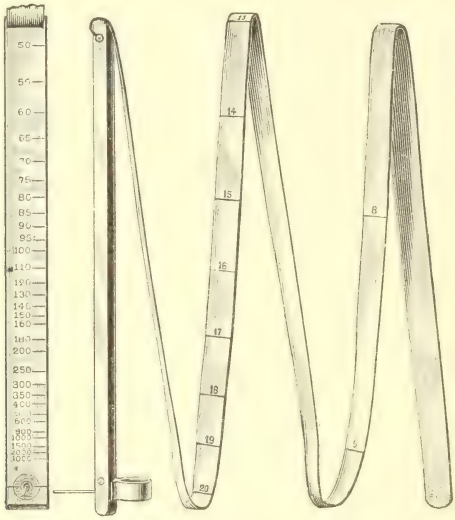


FIG. 8.—New folding turbidity stick.

bidity and color are merely suggestions. It was not intended that the color curves of the Catskill and Tenmile should turn so far to the left at the upper part.

GAGE HEIGHTS AND DISCHARGE MEASUREMENTS.

In the following tables are given the mean daily gage heights during the years 1901 and 1902 at the stations established upon the Catskill, Esopus, Rondout, and Fishkill creeks, and Wallkill, Tenmile, and Housatonic rivers.

Following these tables are records of current-meter discharge measurements on these streams. These observations and measurements are being continued.

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.55	2.92	2.8	2.7	2.65	17	3.85	2.4	2.82	3.02	2.77	5.0
2	.....	2.6	3.0	2.75	2.7	2.65	18	3.78	2.52	2.97	2.97	2.75	4.4
3	.....	2.55	3.22	2.7	2.65	2.65	19	4.35	2.62	2.97	2.9	2.75	4.0
4	2.75	2.4	3.27	2.7	2.67	3.3	20	3.58	2.67	2.82	2.85	2.75	3.85
5	2.9	2.4	3.05	2.67	2.67	3.3	21	3.17	2.75	2.8	2.82	2.75	3.9
6	3.3	2.5	2.92	2.67	2.65	3.32	22	2.67	3.05	2.8	2.8	2.75	4.0
7	3.6	3.35	2.87	2.62	2.7	3.32	23	2.95	3.22	2.77	2.8	2.7	4.0
8	3.63	3.05	2.9	2.65	2.7	3.3	24	3.0	3.45	2.72	2.8	2.7	4.07
9	3.35	2.87	2.87	2.6	2.65	3.35	25	3.02	3.55	2.67	2.8	2.7	3.45
10	3.07	2.8	2.82	2.65	2.65	5.35	26	2.82	3.2	2.65	2.8	2.7	3.4
11	3.53	2.77	2.8	2.6	2.65	4.62	27	2.7	2.95	2.65	2.75	2.65	3.4
12	3.45	2.65	2.75	2.6	2.67	4.45	28	2.7	2.8	2.7	2.75	2.65	3.5
13	3.23	2.55	2.77	2.65	2.8	3.95	29	2.72	2.7	2.8	2.75	2.65	3.85
14	3.0	2.5	2.72	2.8	3.02	6.95	30	2.65	2.65	2.82	2.7	2.65	4.5
15	2.85	2.5	2.7	3.1	2.85	12.8	31	2.6	2.6	.....	2.7	.....	4.4
16	2.9	2.5	2.75	3.15	2.82	5.6							

Mean daily gage height of Catskill Creek at South Cairo, N. Y., for 1902

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	4.30	11.70	5.35	4.10	2.95	3.48	4.50	2.90	6.18	4.30	3.60
2	.....	5.05	9.68	5.88	3.95	2.88	3.28	5.58	2.83	5.63	4.15	3.63
3	.....	5.20	6.70	4.95	3.93	2.80	3.13	4.38	2.75	5.20	4.05	3.80
4	.....	4.45	6.80	4.88	3.88	2.83	3.10	4.13	2.73	4.80	3.95	4.18
5	4.40	4.40	6.35	4.90	3.83	2.88	3.08	3.85	2.73	4.60	3.90	4.00
6	4.20	4.40	5.40	4.65	3.78	2.88	4.45	4.45	2.70	4.53	3.83	4.00
7	4.05	4.30	4.10	4.40	3.73	2.85	4.20	4.20	2.73	4.40	3.77	3.93
8	4.80	4.25	4.10	4.60	3.70	2.90	3.48	3.93	2.78	4.23	3.73	3.80
9	3.70	4.20	4.30	11.65	3.60	2.80	3.80	3.80	2.90	4.05	3.65	3.70
10	3.55	4.25	5.20	8.25	3.50	2.75	3.65	3.65	3.68	3.90	3.55	4.05
11	3.40	4.40	5.75	6.98	3.40	2.70	3.60	3.55	3.55	3.93	3.50	4.40
12	3.30	4.50	9.10	6.48	3.30	2.65	3.55	3.55	3.28	5.08	3.55	4.13
13	3.30	4.70	9.20	5.50	3.28	2.78	2.95	3.45	3.40	4.60	3.63	4.00
14	3.30	4.95	7.50	4.95	3.23	2.75	2.80	3.15	3.53	4.25	3.53	4.00
15	3.20	3.10	5.45	4.78	3.20	2.70	2.80	3.20	3.35	4.15	3.50	3.95
16	3.30	3.20	7.40	4.58	3.05	2.75	2.75	3.15	3.18	4.25	3.40	4.53
17	3.20	3.40	9.43	4.35	3.00	2.90	2.70	3.05	3.05	3.93	3.40	6.35
18	3.00	3.50	6.85	4.25	2.95	2.88	2.65	2.93	2.95	3.83	3.33	5.43
19	2.90	3.60	4.15	4.20	2.90	2.78	2.70	3.05	2.98	3.80	3.30	5.00
20	2.90	3.80	4.50	4.20	2.95	2.85	4.40	3.10	3.25	3.83	3.28	4.80
21	3.10	3.80	4.00	4.13	2.95	2.80	7.25	3.03	3.48	3.73	3.30	6.65
22	9.85	3.80	4.55	4.10	2.83	2.80	6.50	2.98	3.58	3.73	3.20	8.48
23	5.90	3.50	5.58	4.03	2.78	2.80	6.53	2.93	3.18	3.60	3.20	6.70
24	4.80	3.20	5.48	3.95	2.90	2.78	6.18	2.83	3.10	3.63	3.15	5.13
25	4.40	3.40	5.05	3.90	2.95	2.70	7.08	2.75	3.25	3.60	3.20	4.85
26	4.03	3.50	4.93	3.80	2.85	2.68	7.85	2.70	3.58	3.50	3.30	6.65
27	3.85	4.83	4.83	3.83	3.10	2.65	4.05	2.70	4.35	3.55	3.85	4.35
28	3.58	9.15	5.03	3.73	3.33	2.60	4.20	2.73	[a]4.70	5.90	4.13	4.20
29	3.70	.....	5.73	3.95	3.25	2.80	4.40	2.85	9.95	5.30	3.80	4.13
30	4.25	.....	5.93	4.10	3.13	3.88	4.38	2.98	7.20	4.70	3.63	3.95
31	4.30	.....	5.43	.....	3.00	.....	4.25	3.08	.....	4.45	.....	3.85

[a] 12 o'clock midnight, 16.1.

Mean daily gage height of Esopus Creek, at Kingston, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.97	6.47	4.52	4.62	4.6	17	4.05	4.37	5.0	4.47	4.3	10.55
2	.....	3.95	6.3	4.62	4.52	4.52	18	4.05	4.54	5.27	4.42	4.37	9.05
3	.....	3.9	6.67	4.7	4.35	4.77	19	4.6	4.5	5.07	4.6	4.52	8.1
4	..	4.95	6.27	4.52	4.37	5.45	20	4.15	4.77	5.35	4.77	4.5	8.0
5	4.3	3.95	5.8	4.42	4.55	4.62	21	4.1	5.95	5.17	4.77	4.47	7.75
6	4.35	3.7	5.57	4.3	4.47	4.67	22	3.9	6.62	4.77	4.67	4.52	7.2
7	4.3	3.95	5.42	4.47	4.57	4.72	23	4.05	5.92	4.92	4.67	4.45	6.85
8	4.4	7.0	5.02	4.57	4.47	4.65	24	4.0	7.35	4.77	4.62	4.52	6.7
9	4.4	5.72	5.17	4.5	4.32	.....	25	3.9	7.67	4.5	4.62	4.62	6.5
10	4.25	5.17	4.95	4.52	4.32	5.6	26	3.97	6.52	4.37	4.52	4.6	6.35
11	4.25	5.05	5.02	4.47	4.45	11.5	27	3.92	6.02	4.5	4.42	4.57	6.25
12	4.3	4.87	4.87	4.4	4.57	9.72	28	3.85	5.87	4.72	4.45	4.77	6.0
13	4.3	4.72	4.9	4.5	4.6	7.35	29	3.72	5.72	4.45	4.57	5.45	7.55
14	4.2	4.6	4.87	4.52	4.45	8.12	30	4.2	5.45	4.42	4.47	4.52	11.65
15	3.95	4.42	4.72	4.57	4.37	21.37	31	4.25	5.22	.....	4.6	.....	9.45
16	4.2	4.42	4.75	4.65	4.43	15.2							

Mean daily gage height of Esopus Creek at Kingston, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.20	7.25	12.10	9.35	8.95	4.85	6.38	7.09	4.45	13.38	7.28	5.90
2	10.35	7.45	16.82	8.69	8.18	4.83	6.19	7.95	4.48	11.68	6.75	5.70
3	9.95	9.35	15.75	8.05	7.78	4.76	6.00	7.10	4.43	10.10	5.83	6.19
4	8.40	7.72	11.07	7.64	7.70	4.83	6.40	6.90	4.33	9.50	6.55	6.43
5	7.65	7.52	9.45	7.33	7.43	4.70	5.99	6.53	4.38	8.60	6.55	6.33
6	7.30	7.16	8.95	7.03	7.11	4.73	6.19	7.08	4.33	9.64	6.25	6.18
7	6.95	6.70	7.90	7.18	6.98	4.55	6.16	6.90	4.38	8.68	6.47	6.35
8	6.65	6.47	7.68	7.28	6.74	4.63	6.03	3.43	4.38	8.18	6.35	6.60
9	6.50	6.14	8.85	13.10	6.55	4.63	5.80	6.18	4.38	7.85	6.13	6.45
10	6.40	6.25	9.20	13.86	6.40	4.68	5.58	5.88	7.68	7.40	6.00	6.00
11	6.35	5.94	9.05	11.60	6.23	4.58	5.50	5.83	6.00	7.15	7.85	6.35
12	5.88	5.88	9.80	10.22	6.10	4.45	5.34	6.25	5.49	9.10	7.95	6.55
13	6.00	5.77	11.85	9.41	5.96	4.53	5.15	5.73	5.53	8.47	5.85	6.35
14	5.93	5.60	11.82	8.78	5.88	4.58	5.05	5.58	6.18	8.00	5.78	6.40
15	5.60	5.58	9.98	8.25	5.70	4.40	4.98	5.38	5.85	7.60	5.73	6.43
16	5.58	5.53	9.33	7.90	5.70	4.46	4.99	5.30	5.53	7.33	5.63	6.65
17	5.59	5.63	[a]18.28	7.58	5.50	4.78	4.89	5.08	5.30	7.15	5.60	16.20
18	5.30	5.39	13.10	7.35	5.33	4.94	4.80	5.10	5.13	6.95	5.60	12.86
19	5.50	5.45	10.13	7.10	5.38	4.63	4.78	4.98	5.08	6.75	5.54	11.00
20	5.37	5.30	9.20	6.93	5.39	4.60	6.88	4.98	5.30	6.73	5.46	9.95
21	4.95	5.35	8.62	6.80	5.28	4.81	10.00	4.88	6.88	6.47	5.45	8.55
22	12.73	5.36	8.25	6.78	5.13	5.55	9.50	4.85	6.28	6.30	5.38	15.60
23	10.88	5.30	8.20	6.93	5.03	5.13	9.28	4.78	5.88	6.20	5.36	12.80
24	8.88	5.36	7.87	6.88	5.00	4.93	8.38	4.65	5.68	6.13	5.36	10.40
25	8.00	5.39	7.63	6.58	4.88	4.81	8.58	4.70	5.68	6.30	5.20	9.35
26	7.53	6.45	7.43	6.36	5.20	4.93	8.68	4.65	7.00	5.87	5.30	8.70
27	8.63	9.30	7.28	6.35	5.20	5.15	8.01	4.55	10.35	5.78	6.00	8.28
28	8.08	9.37	7.17	6.20	5.58	4.84	7.75	4.65	9.48	7.83	6.60	8.75
29	7.72	.....	11.65	5.98	5.25	4.81	7.19	4.70	[b]22.43	8.35	6.10	9.10
30	7.82	.....	12.55	9.81	5.03	7.10	7.68	4.60	17.35	7.75	5.88	8.97
31	7.48	.....	10.45	.....	5.03	.....	7.35	4.63	.....	7.50	.....	8.05

[a] Highest water at 1.30 p. m., 25.25.

[b] Highest water at 1.30 p. m., 18.30.

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	7.57	7.62	7.26	6.5	6.55	17	6.3	6.5	6.67	7.1	6.55	8.95
2	.....	5.5	7.95	6.85	6.5	6.4	18	6.85	6.75	7.05	7.0	6.55	8.04
3	.....	6.3	7.8	6.95	6.5	6.5	19	6.55	7.0	6.85	6.9	6.55	7.77
4	.....	6.25	7.61	6.8	6.45	6.85	20	6.48	6.95	6.65	6.8	6.5	7.55
5	.....	6.17	7.42	6.7	6.4	6.87	21	6.47	8.75	6.55	6.72	6.4	7.55
6	.....	6.35	6.97	6.62	6.4	6.85	22	6.37	8.15	6.52	6.7	6.35	7.57
7	.....	9.75	6.87	6.55	6.4	6.92	23	6.4	7.5	6.47	6.7	6.4	7.95
8	6.5	7.35	6.77	6.55	6.4	7.0	24	6.35	9.0	6.42	6.6	6.5	7.75
9	6.4	6.92	6.67	6.52	6.4	7.2	25	6.35	9.4	6.4	6.6	7.6	7.22
10	6.25	6.62	6.6	6.45	6.4	9.2	26	6.3	8.1	6.35	6.6	7.25	7.12
11	6.2	7.17	6.6	6.42	6.37	9.25	27	6.47	7.47	6.32	6.6	6.97	7.0
12	6.25	7.42	6.65	6.42	6.45	8.22	28	6.42	7.15	6.3	6.65	6.87	7.35
13	6.3	6.87	6.72	6.5	6.95	7.75	29	6.37	6.95	7.05	6.5	6.8	9.1
14	6.33	6.55	6.57	7.25	6.8	8.97	30	6.67	7.42	7.41	6.5	6.8	12.12
15	6.3	6.50	6.5	7.72	6.62	16.75	31	6.72	6.72	.....	6.5	.....	10.0
16	6.38	6.52	6.62	7.37	6.6	10.6							

Mean daily gage height of Rondout Creek at Rosendale, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.73	8.98	17.20	8.18	8.25	6.58	7.08	7.70	6.25	10.03	7.25	6.73
2	7.90	8.95	14.23	7.85	7.70	6.48	6.90	8.35	6.20	9.28	7.05	6.70
3	7.90	9.75	12.53	7.58	7.70	6.55	6.98	7.60	6.13	8.43	7.03	6.90
4	7.90	9.35	9.75	7.58	7.75	6.63	7.70	7.28	6.15	7.90	7.00	7.20
5	7.90	9.70	8.70	7.35	7.50	6.48	7.23	7.08	6.10	7.80	6.90	6.88
6	7.83	9.25	8.05	7.25	7.33	6.40	7.13	7.25	6.18	8.78	6.87	6.80
7	7.58	9.00	7.95	7.60	7.28	6.48	7.00	7.33	6.20	8.00	6.95	6.95
8	7.28	8.83	7.65	8.10	7.15	6.45	6.88	7.03	6.20	7.65	6.85	6.98
9	7.13	8.58	9.40	12.28	7.03	6.48	6.85	6.93	6.23	7.38	6.80	6.88
10	7.08	8.05	9.70	11.40	6.93	6.38	6.65	6.83	7.00	7.18	6.78	7.10
11	7.10	8.18	9.30	9.75	6.88	6.30	6.58	6.80	6.58	6.95	6.73	7.08
12	7.35	8.05	9.70	9.15	6.88	6.35	6.53	6.90	6.40	9.75	6.73	7.00
13	6.95	7.98	11.05	8.63	6.83	6.35	6.50	6.80	6.45	8.65	6.73	6.95
14	6.73	7.88	10.15	8.15	6.68	6.38	6.45	6.70	6.68	8.00	6.70	7.15
15	6.83	7.80	9.15	7.85	6.63	6.35	6.35	6.55	6.48	7.57	6.70	7.50
16	6.90	7.65	8.80	7.65	6.70	6.35	6.40	6.58	6.35	7.35	6.70	8.35
17	6.78	7.53	13.10	7.50	6.60	6.50	6.33	6.50	6.25	7.23	6.65	12.95
18	6.70	7.60	9.95	7.38	6.63	6.45	6.30	6.45	6.20	7.07	6.65	10.00
19	6.78	7.35	8.65	7.25	6.60	6.30	6.33	6.40	6.18	7.07	6.68	8.80
20	6.70	7.43	8.25	7.18	6.60	6.43	7.53	6.40	6.25	7.00	6.65	8.30
21	6.73	7.43	8.08	7.10	6.58	6.43	8.93	6.38	6.50	6.95	6.65	8.35
22	14.68	7.40	8.00	7.05	6.50	7.10	9.18	6.48	6.40	6.90	6.65	13.45
23	9.83	7.43	7.88	7.00	6.48	6.70	8.38	6.40	6.23	6.80	6.60	10.58
24	8.35	7.48	7.80	6.90	6.45	6.50	[a]9.94	6.40	6.25	6.80	6.60	9.55
25	7.85	7.55	7.63	6.88	6.46	6.40	10.34	6.33	6.45	6.80	6.55	8.50
26	7.68	8.23	7.45	6.98	6.80	6.43	8.95	6.30	9.40	6.73	6.70	8.10
27	8.95	10.68	7.38	6.95	6.88	6.50	8.23	6.28	9.75	6.63	6.75	8.87
28	7.75	12.10	7.33	6.83	7.20	6.43	7.80	6.25	8.68	9.38	6.90	7.45
29	8.00	.....	9.85	6.78	6.85	6.45	7.38	6.33	[b]14.09	8.60	6.88	7.27
30	8.18	.....	9.53	9.38	6.60	7.70	7.80	6.30	10.78	7.83	6.80	7.20
31	8.60	.....	8.63	.....	6.63	.....	7.33	6.30	.....	7.45	.....	7.20

[a] Highest water, 12.65, at 7 p. m.

[b] Highest water, 15.6, at 3 p. m.

Estimated diversion from Rondout Creek to Delaware and Hudson Canal, Rosendale, N. Y., 1902, in second-feet.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	.....	15.5	22.6	.....	24.2	26.0	.....	22.6	22.5	.....
2	.....	.....	.....	17.7	15.0	25.2	23.8	25.6	25.3	22.4	.....	.....
3	.....	.....	.....	21.5	24.6	20.8	23.1	.....	22.5	26.1	21.0	.....
4	.....	.....	.....	22.0	.....	11.6	.....	23.8	24.3	25.8	23.5	.....
5	.....	.....	.....	17.9	27.6	25.3	24.1	24.5	25.3	.....	21.5	.....
6	.....	.....	.....	.....	23.1	19.5	.....	22.5	25.8	22.2	23.3	.....
7	.....	.....	.....	20.4	24.8	21.8	23.1	24.5	.....	23.1	24.2	.....
8	.....	.....	.....	20.2	24.3	.....	22.7	23.8	25.0	22.4	24.8	.....
9	.....	.....	.....	18.4	24.6	23.8	24.3	24.0	23.5	21.9	.....	.....
10	.....	.....	.....	14.3	24.5	35.9	25.3	.....	24.3	22.8	.....	.....
11	.....	.....	.....	20.7	.....	24.9	26.1	24.0	24.3	22.1	.....	.....
12	.....	.....	.....	19.2	24.3	33.8	21.8	24.5	25.1	.....	.....	.....
13	.....	.....	.....	.....	24.1	27.5	.....	24.6	22.2	20.4	.....	.....
14	.....	.....	.....	25.4	25.0	23.6	25.3	26.0	.....	20.6	.....	.....
15	.....	.....	.....	25.7	24.1	.....	25.3	24.8	26.5	20.5	.....	.....
16	.....	.....	.....	24.2	24.5	22.3	24.2	24.5	25.6	19.5	.....	.....
17	.....	.....	.....	25.1	22.8	22.6	26.0	.....	25.8	19.5	.....	.....
18	.....	.....	.....	26.1	.....	24.3	25.1	25.5	23.3	19.7	.....	.....
19	.....	.....	.....	25.6	24.3	23.8	22.7	24.3	24.8	.....	.....	.....
20	.....	.....	.....	.....	24.6	23.9	.....	23.8	22.0	21.3	.....	.....
21	.....	.....	.....	25.9	23.1	24.4	23.8	25.1	.....	23.5	.....	.....
22	.....	.....	.....	26.7	23.6	.....	25.6	25.6	24.3	21.0	.....	.....
23	.....	.....	15.8	24.1	25.6	22.1	22.8	24.3	23.8	21.2	.....	.....
24	.....	.....	11.4	23.3	24.3	20.1	20.6	.....	24.0	23.0	.....	.....
25	.....	.....	12.3	23.4	.....	22.6	19.0	22.8	25.1	20.4	.....	.....
26	.....	.....	15.3	22.8	21.1	22.8	22.8	22.2	22.8	.....	.....	.....
27	.....	.....	16.9	.....	28.0	19.8	.....	25.1	22.6	22.8	.....	.....
28	.....	.....	16.4	27.1	26.5	22.6	25.6	22.5	.....	23.8	.....	.....
29	.....	.....	.....	25.2	26.3	.....	21.6	25.8	20.3	24.3	.....	.....
30	.....	.....	.....	25.8	20.7	26.7	23.6	23.0	22.1	23.0	.....	.....
31	.....	.....	21.8	.....	24.1	.....	26.4	.....	.....	25.0	.....	.....
Mean	.....	.....	.....	22.5	24.0	23.7	23.8	24.3	24.0	22.2	.....	.....

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	6.19	9.20	7.45	6.00	6.25	17	6.37	6.75	7.05	7.50	6.25	13.10
2	.....	5.90	9.85	7.25	6.00	6.05	18	7.15	9.25	7.62	7.27	6.05	13.65
3	.....	5.97	9.75	7.15	6.00	6.00	19	7.98	11.15	7.65	7.15	6.15	13.75
4	.....	6.00	9.35	7.00	6.00	6.20	20	7.20	10.15	7.45	6.95	6.35	12.95
5	.....	6.45	8.55	6.95	6.05	6.35	21	6.50	10.25	7.30	6.70	7.30	11.70
6	.....	6.45	8.35	6.85	6.10	6.65	22	6.35	10.25	7.10	6.45	8.10	10.70
7	7.27	12.05	8.65	6.65	6.00	6.60	23	6.25	10.15	6.95	6.32	8.65	10.45
8	7.23	11.25	7.70	6.47	5.95	7.30	24	6.05	9.70	6.82	6.30	8.35	10.15
9	6.93	9.30	7.47	6.35	5.85	10.00	25	6.00	14.30	6.65	6.20	8.10	9.55
10	6.65	9.15	7.45	6.30	5.75	12.30	26	6.00	12.00	6.50	6.12	7.45	9.00
11	6.53	9.10	7.25	6.30	5.65	11.70	27	5.85	11.25	6.35	6.10	6.95	9.25
12	7.33	8.05	7.05	6.20	5.95	10.30	28	5.85	10.60	6.35	6.10	6.85	9.70
13	7.60	7.70	7.15	6.20	6.40	10.05	29	5.85	9.90	6.65	6.10	6.65	11.80
14	7.15	7.15	6.95	6.35	7.00	10.60	30	5.80	9.15	7.25	6.10	6.45	19.35
15	6.85	7.40	6.65	7.50	6.90	13.30	31	5.95	.....	.....	6.50	.....	19.20
16	6.55	7.10	6.75	7.85	6.55	12.85							

Mean daily gage height of Wallkill River at New Paltz, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	15.15	8.75	23.53	9.35	10.25	7.50	7.25	9.50	6.10	10.25	8.65	6.80
2	13.25	8.75	23.80	8.95	8.95	7.25	7.15	9.10	6.05	10.85	8.35	6.70
3	12.95	10.65	[a]24.65	8.65	9.15	7.05	7.50	8.75	6.00	10.15	8.15	7.50
4	12.10	9.70	22.75	8.20	8.85	6.90	7.58	8.60	5.88	9.65	7.95	7.95
5	10.45	9.75	20.25	8.00	8.35	6.55	7.08	8.30	5.78	9.60	7.65	8.10
6	10.70	8.90	15.20	9.70	7.95	6.35	6.78	7.95	5.70	10.10	7.50	8.55
7	10.20	8.15	13.20	7.70	7.50	6.30	6.53	7.85	5.60	9.45	7.50	8.10
8	8.70	7.85	12.70	8.40	7.45	6.25	6.35	7.65	5.50	9.00	7.65	7.70
9	9.15	7.78	14.90	[b]13.65	7.35	6.30	6.23	7.30	5.50	8.55	7.15	7.70
10	8.85	7.70	16.45	13.50	7.10	6.50	6.10	7.05	6.10	8.40	6.95	7.65
11	8.75	7.55	15.90	12.20	6.80	6.35	6.00	6.90	6.45	8.25	6.75	7.60
12	8.20	7.55	16.10	11.65	6.65	6.30	6.00	6.80	6.30	12.45	6.70	7.60
13	8.05	7.40	17.05	10.65	6.60	6.20	5.90	6.75	6.35	11.90	6.60	7.55
14	8.05	7.35	16.50	9.80	6.55	6.15	5.78	6.68	6.45	10.50	6.60	7.50
15	8.00	7.15	15.00	9.35	6.50	6.10	5.70	6.60	6.25	9.70	6.60	7.50
16	8.00	7.10	14.65	8.65	6.45	6.20	5.70	6.53	6.15	9.35	6.50	7.50
17	7.70	7.20	15.40	8.20	6.35	6.25	5.73	6.43	6.05	9.00	6.50	12.20
18	7.55	7.15	13.75	8.00	6.30	6.15	5.58	6.38	5.95	8.60	6.50	12.25
19	7.50	7.08	11.75	7.85	6.30	6.13	5.55	7.28	5.80	8.60	6.50	12.30
20	7.20	7.00	10.60	7.60	6.30	6.10	6.10	6.20	5.90	8.15	6.50	12.30
21	7.20	7.05	10.30	7.45	6.30	6.13	7.78	6.15	5.90	7.95	6.40	12.95
22	18.50	7.05	10.20	7.35	6.30	6.33	8.65	6.10	5.90	7.65	6.40	19.00
23	17.65	7.10	9.75	7.15	6.25	6.40	7.40	6.05	5.90	7.47	6.65	19.65
24	13.55	7.25	9.60	7.10	6.20	6.35	[c]11.00	6.10	5.90	7.37	6.30	17.20
25	13.15	7.30	9.45	6.95	6.20	6.20	[d]14.00	6.05	6.15	7.15	6.30	16.25
26	12.20	7.75	9.00	6.85	6.45	6.20	9.10	6.00	9.65	6.95	6.35	15.30
27	12.85	11.40	8.50	7.00	8.30	6.10	8.50	6.00	12.00	6.85	7.35	14.20
28	12.65	12.75	8.20	6.75	9.20	6.03	7.80	5.95	11.90	11.65	7.35	14.20
29	11.15	.....	10.20	6.65	8.40	6.13	7.45	8.25	13.45	11.25	7.10	13.80
30	9.50	.....	11.05	[e]11.75	8.30	7.00	7.45	6.95	10.35	9.45	6.95	12.30
31	9.25	.....	9.90	.....	7.90	.....	8.45	6.40	.....	8.95	.....	11.75

[a] Highest water 24.80 at p. m.
[b] Highest water 14.6 at p. m.
[c] Highest water 15.4 at 8 p. m.
[d] Highest water 16.6 at 9 p. m.
[e] Highest water 12.6 at p. m.

Mean daily gage height of Fishkill Creek at Glenham, N. Y., for 1901.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.95	4.57	4.05	3.97	3.90	17	3.73	3.85	4.15	4.55	3.95	6.18
2	.....	3.82	4.60	3.97	3.95	3.98	18	4.23	5.07	4.22	4.40	3.95	5.53
3	.....	3.77	4.47	4.10	3.95	4.05	19	4.00	4.70	4.12	4.32	3.95	5.15
4	.....	3.67	4.42	4.10	3.95	4.08	20	3.90	4.40	4.02	4.22	3.95	4.98
5	.....	3.65	4.30	4.00	3.90	4.10	21	3.77	4.45	4.02	4.20	3.93	4.78
6	.....	3.65	4.15	3.92	3.90	4.25	22	3.70	4.95	4.00	4.15	3.93	4.73
7	.....	4.70	4.17	3.90	3.92	4.28	23	3.65	4.62	3.92	4.12	3.90	4.73
8	3.90	5.55	4.10	3.87	3.95	4.18	24	3.65	4.70	3.90	4.10	3.90	4.55
9	3.90	4.77	4.07	3.85	3.90	4.05	25	3.65	6.40	3.87	4.05	4.35	4.60
10	3.80	4.35	4.02	3.85	3.87	4.73	26	3.62	6.55	3.85	4.00	4.33	4.55
11	3.78	4.12	4.05	3.85	3.87	5.33	27	3.60	5.65	3.80	4.00	4.13	4.85
12	3.83	4.07	4.37	3.80	3.92	4.83	28	3.55	5.20	3.87	4.00	4.03	4.15
13	3.80	4.02	4.32	3.80	4.32	4.60	29	3.57	4.85	3.95	4.00	4.00	5.75
14	3.73	3.90	4.15	4.30	4.17	4.68	30	4.35	4.70	4.20	4.00	3.98	8.28
15	3.70	3.90	4.10	4.85	4.05	6.78	31	4.15	4.57	.....	3.97	.....	7.50
16	3.65	3.82	4.25	4.82	4.00	7.45							

Mean daily gage height of Fishkill Creek, at Glenham, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.05	5.00	13.00	4.90	5.48	3.83	3.70	3.80	2.90	4.25	4.40	3.70
2	5.65	4.75	10.00	4.78	4.93	3.70	3.53	3.70	2.80	4.20	4.33	3.73
3	5.50	5.63	8.78	4.68	4.70	3.60	3.45	3.60	2.95	4.00	4.20	3.88
4	5.30	5.55	6.70	4.60	4.73	3.70	3.85	3.60	2.73	3.83	4.15	4.03
5	5.18	5.58	5.80	4.53	4.63	3.70	3.60	3.50	2.90	3.83	4.05	3.98
6	4.95	5.28	4.95	4.45	4.45	3.55	3.70	3.43	2.95	4.20	4.03	3.70
7	4.80	5.25	5.05	4.53	4.35	3.50	3.70	3.48	2.90	4.20	4.00	3.70
8	4.70	5.00	5.15	4.63	4.30	3.85	3.55	3.40	2.95	3.93	4.00	3.80
9	4.65	5.18	5.90	5.13	4.20	3.85	3.45	3.40	3.00	3.85	3.93	3.98
10	4.63	5.05	7.75	5.65	4.10	3.75	3.38	3.30	3.33	3.78	3.90	4.05
11	4.60	4.75	6.95	5.53	3.90	3.60	3.40	3.50	3.25	3.70	3.88	3.85
12	4.58	4.80	6.50	5.28	3.98	3.50	3.30	3.85	3.08	4.95	3.88	3.90
13	4.75	4.60	6.70	5.05	3.95	3.40	3.23	3.65	3.30	5.03	3.88	4.05
14	5.00	4.40	6.63	4.90	3.90	3.43	3.20	3.48	3.23	4.08	3.88	4.10
15	4.70	4.33	5.98	4.80	3.90	3.50	3.13	3.40	3.20	4.35	3.80	4.30
16	4.35	4.25	5.65	4.70	3.90	3.50	3.13	3.35	3.15	4.20	3.83	4.40
17	4.28	4.48	6.73	4.60	3.80	3.95	3.10	3.28	3.15	4.80	3.80	6.65
18	4.25	4.38	6.45	4.58	3.70	3.70	3.10	3.20	3.18	4.00	3.70	7.55
19	4.25	4.33	5.70	4.50	3.75	3.50	3.08	3.20	3.00	4.00	3.70	6.50
20	4.18	4.35	5.20	4.40	3.80	3.53	3.20	3.15	3.05	3.95	3.68	5.98
21	4.18	4.38	5.30	4.35	3.83	3.50	4.15	3.10	3.03	3.90	3.63	5.50
22	5.88	4.85	5.23	4.30	3.68	3.75	4.70	3.15	3.15	3.80	3.60	7.75
23	6.55	4.85	5.13	4.23	3.68	3.60	4.65	3.10	3.08	3.80	3.60	8.05
24	5.15	4.90	5.00	4.15	3.60	3.50	4.10	3.10	3.13	3.70	3.63	7.00
25	4.75	4.70	4.85	4.05	3.60	3.40	4.18	3.15	2.95	3.75	3.63	5.95
26	4.63	4.85	4.75	4.05	4.20	3.50	4.10	3.05	3.48	3.73	3.68	5.60
27	5.00	5.88	4.70	4.13	4.15	3.40	4.05	3.00	3.60	3.70	3.95	5.40
28	5.00	7.10	4.55	4.08	4.58	3.30	3.90	3.00	3.60	4.65	3.88	5.05
29	4.95		4.85	4.00	4.23	3.35	3.80	2.95	4.80	5.43	3.80	4.93
30	5.05		5.40	4.83	4.03	4.08	4.20	2.95	4.75	4.93	3.70	4.90
31	4.95		5.05		3.90		3.95	2.90		4.55		4.77

Mean daily gage height of Tenmile River at Dover Plains, N. Y., for 1901.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1		5.02	4.95	4.65	17	5.00	6.17	5.05	8.15
2		4.80	4.90	4.67	18	5.30	5.87	5.90	7.20
3		5.00	4.90	4.95	19	5.00	5.62	4.87	6.85
4		5.00	4.85	5.50	20	4.85	5.50	4.87	6.35
5		4.87	4.87	6.05	21	4.80	5.47	4.85	5.95
6		4.85	4.87	5.40	22	4.80	5.40	4.79	5.75
7		4.75	4.85	5.02	23	4.70	5.35	4.75	5.92
8		4.65	4.80	4.80	24	4.60	5.27	4.75	5.90
9		4.65	4.77	4.77	25	4.57	5.20	5.20	5.95
10		4.65	4.75	6.35	26	4.50	5.00	5.10	6.40
11		4.65	4.67	6.72	27	4.55	5.02	4.90	6.47
12		4.65	4.97	6.35	28	4.37	5.05	4.95	6.50
13		4.57	5.90	6.12	29	4.77	4.97	4.85	10.70
14		6.27	5.50	6.47	30	5.50	4.95	4.72	12.30
15		6.82	5.27	11.17	31		4.92		10.22
16		6.42	5.10	9.50					

Mean daily gage height of Tenmile River at Dover Plains, N. Y., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.70	5.40	14.15	6.60	6.95	4.55	4.45	5.10	3.90	5.78	5.75	4.45
2	7.00	6.10	14.10	6.45	6.95	4.50	4.25	4.88	3.83	5.85	5.50	4.48
3	6.95	6.95	[a]11.43	6.25	6.50	4.40	4.35	4.65	3.80	5.43	5.43	4.80
4	6.10	6.08	8.35	5.98	6.20	4.55	5.53	4.63	3.90	5.10	5.33	4.90
5	6.08	5.50	6.95	5.80	6.05	4.48	4.38	4.53	3.83	5.30	5.30	4.73
6	6.15	5.35	5.90	5.90	5.90	4.35	4.60	4.43	3.80	5.85	5.25	4.78
7	6.10	5.10	6.25	6.13	5.75	4.25	4.63	4.65	3.85	5.38	5.10	4.80
8	5.80	5.10	6.25	6.40	5.55	4.48	4.33	4.60	3.88	5.13	5.08	4.85
9	5.65	4.95	8.90	6.80	5.35	4.55	4.38	4.45	3.95	4.90	5.00	5.13
10	5.55	4.90	10.60	7.60	5.23	4.48	4.23	4.43	4.23	4.83	4.93	5.08
11	5.60	5.10	9.15	7.10	4.95	4.30	4.20	5.68	3.95	5.00	4.83	4.85
12	5.55	5.10	8.70	6.60	4.85	4.20	4.10	5.03	3.90	6.10	4.78	4.80
13	5.38	4.80	9.10	6.30	4.85	4.75	4.15	5.95	4.10	6.93	4.83	4.80
14	5.25	6.75	8.40	6.15	4.80	4.70	3.90	4.78	4.23	5.87	4.80	4.93
15	5.25	5.25	7.70	6.10	4.80	4.35	3.88	4.68	4.13	5.63	4.83	5.08
16	4.93	5.15	7.30	5.90	4.75	4.45	4.30	4.23	4.03	5.43	4.73	6.15
17	4.65	5.05	8.15	5.88	4.65	4.65	4.18	4.18	3.88	5.25	4.65	10.47
18	5.05	5.05	7.60	5.68	4.60	4.45	3.88	4.15	3.88	5.15	.....	9.13
19	5.10	5.00	6.55	5.58	4.65	4.28	4.03	4.15	4.03	5.27	4.60	8.28
20	5.05	4.85	6.13	5.45	4.68	4.15	4.65	4.18	4.28	5.20	4.53	7.70
21	5.05	4.75	6.10	5.35	4.58	4.40	6.98	4.25	4.33	4.90	4.55	7.74
22	11.95	4.68	6.15	5.23	4.50	4.60	7.15	4.23	4.13	4.80	4.58	11.50
23	8.10	4.40	6.20	5.13	4.40	4.38	6.35	4.10	4.15	4.75	4.55	10.65
24	6.35	4.50	6.25	5.03	4.30	4.33	5.75	4.08	4.08	4.73	4.53	8.58
25	5.80	4.65	6.05	4.95	4.30	4.15	5.68	4.08	4.05	4.65	4.58	7.95
26	5.70	5.83	5.90	4.95	5.05	4.10	5.50	3.98	4.08	4.55	4.70	7.48
27	7.80	8.45	5.85	5.30	5.30	4.05	5.30	3.93	4.65	4.60	4.93	7.05
28	7.45	9.73	7.43	5.25	5.50	4.05	5.40	3.85	6.50	7.05	4.78	.....
29	6.55	.....	7.60	5.30	5.18	4.10	5.25	3.83	7.75	7.10	4.65	.....
30	6.25	.....	7.30	7.00	4.80	4.70	5.65	3.80	5.98	6.37	4.33	.....
31	5.50	.....	6.90	.....	4.70	.....	5.25	3.85	.....	6.00	.....	.....

[a] Readings on new gage from this date, datum 0.33 above former gage.

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1900.

Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.
1	.....	3.2	4.9	17	.....	3.6	.....
2	.....	3.1	4.6	18	.....	3.5	.....
3	.....	3.1	4.3	19	.....	3.6	.....
4	.....	2.9	4.2	20	.....	3.7	.....
5	.....	3.0	5.6	21	.....	4.1	.....
6	.....	2.9	5.8	22	.....	4.0	.....
7	.....	2.8	5.4	23	2.9	3.9	4.8
8	.....	3.2	5.1	24	3.1	3.9	5.1
9	.....	3.5	4.9	25	3.2	3.8	4.3
10	.....	4.1	4.5	26	3.1	4.6	4.2
11	.....	3.9	4.2	27	3.1	5.5	4.1
12	.....	3.7	4.2	28	3.1	5.4	4.2
13	.....	3.6	4.2	29	3.1	5.1	4.0
14	.....	3.7	4.2	30	3.0	4.9	3.9
15	.....	3.7	.....	31	.....	.....	4.2
16	.....	3.7	.....				

Daily gage height of Housatonic River at Gaylordsville, Conn., for 1901.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.40	3.20	3.30	5.30	6.20	6.20	3.60	3.50	4.30	4.30	4.00	4.00
2	4.00	3.30	3.50	5.30	6.20	6.00	3.50	3.70	4.40	4.20	4.20	4.10
3	(a)	3.30	3.60	5.30	6.40	5.70	3.80	3.50	4.70	4.50	4.00	4.20
4	(a)	3.30	3.60	6.10	6.30	5.50	3.90	3.40	4.60	4.60	3.80	4.10
5	(a)	3.10	4.10	6.60	6.00	5.50	3.70	3.30	4.60	4.40	3.70	4.00
6	4.50	3.00	3.90	6.50	5.60	5.20	4.00	3.30	4.40	4.20	4.10	4.00
7	4.50	3.40	3.90	7.30	5.50	5.20	4.00	3.90	4.40	4.00	3.80	3.90
8	4.40	3.50	3.60	8.30	5.30	5.50	3.80	4.80	4.40	3.90	3.80	3.80
9	4.20	3.40	3.50	8.00	5.20	5.50	3.80	4.40	4.00	4.00	3.80	3.90
10	4.40	3.70	7.50	7.80	5.20	5.40	3.80	4.10	3.90	4.00	3.70	5.00
11	4.10	3.50	8.20	7.20	5.70	5.20	3.90	4.00	4.00	3.80	3.50	5.50
12	4.70	3.30	7.50	6.70	6.30	4.90	4.00	3.90	4.20	3.80	3.60	5.90
13	4.00	3.40	6.00	6.50	6.10	4.80	4.00	3.70	4.00	3.80	4.80	5.70
14	3.50	3.70	5.50	6.10	6.00	4.60	3.90	3.70	4.00	5.20	4.90	5.80
15	3.70	3.60	5.60	5.90	5.60	5.20	3.60	3.60	4.00	6.70	4.70	8.90
16	3.80	3.40	5.60	5.90	5.50	4.70	3.50	3.70	4.10	6.00	4.60	8.20
17	4.40	3.40	4.60	5.50	5.30	4.50	3.70	3.60	4.10	5.80	4.50	7.80
18	4.00	3.40	4.60	5.30	5.30	4.20	3.60	3.70	4.70	5.30	4.40	7.50
19	3.50	3.20	4.80	5.20	5.80	4.30	3.60	4.00	4.50	5.10	4.20	6.80
20	3.40	3.30	4.80	5.20	6.20	4.20	3.60	3.80	4.40	4.90	4.30	6.10
21	3.80	3.40	10.00	7.30	6.20	4.10	3.60	4.10	4.20	4.80	4.20	5.60
22	3.60	3.50	8.70	9.30	5.80	4.00	3.50	4.70	4.20	4.60	4.20	5.10
23	3.70	3.40	7.40	8.40	5.80	4.30	3.40	4.80	4.00	4.50	4.10	4.90
24	3.50	3.20	7.10	8.50	5.60	4.70	3.60	4.80	3.80	4.40	4.20	5.20
25	3.60	3.30	6.60	8.80	6.80	4.60	3.60	6.80	3.90	4.30	4.60	5.20
26	3.70	3.00	6.60	7.85	6.70	4.30	3.50	6.70	3.80	4.30	4.80	5.00
27	3.80	3.40	7.20	7.20	6.80	4.20	3.50	5.70	3.80	4.20	4.50	5.30
28	3.70	3.30	6.90	6.90	6.80	4.00	3.50	5.20	3.80	4.00	4.00	5.10
29	3.50	.....	6.60	7.00	6.90	4.00	3.50	4.80	3.90	4.00	4.00	6.30
30	3.50	.....	6.20	6.40	6.80	3.80	3.40	4.60	4.40	4.30	4.20	9.40
31	3.40	.....	5.80	.....	6.60	.....	3.70	4.40	.....	4.10	.....	7.60

[a] Frozen.

Mean daily gage height of Housatonic River at Gaylordsville, Conn., for 1902.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.10	4.90	14.30	6.80	6.80	4.70	4.80	4.80	3.80	5.50	5.50	4.10
2	6.50	4.90	10.80	6.60	6.30	4.40	4.60	4.65	3.55	5.50	5.30	4.15
3	5.90	5.40	9.90	6.80	6.10	4.40	4.40	4.65	3.50	5.25	5.00	4.40
4	5.30	4.90	10.20	5.80	5.90	4.60	4.70	4.45	3.60	5.15	4.95	4.60
5	5.20	4.80	7.80	5.80	5.60	4.90	4.50	4.30	3.65	5.00	4.85	4.60
6	5.30	4.60	6.80	5.50	5.50	4.80	4.50	4.40	3.55	5.15	4.75	4.30
7	5.30	4.50	6.50	5.50	5.50	4.60	4.80	4.60	3.65	5.00	4.65	4.35
8	5.20	4.40	6.80	5.70	5.30	4.60	5.00	4.55	3.50	4.85	4.60	4.30
9	5.30	8.50	6.80	6.10	5.20	4.40	4.70	4.55	3.55	4.70	4.50	3.45
10	5.10	6.80	7.50	6.80	4.90	4.60	4.50	4.45	4.00	4.55	4.35	3.55
11	5.00	7.00	2.20	6.90	5.00	4.50	4.40	4.50	4.00	4.40	4.30	3.70
12	4.90	8.00	7.70	6.80	4.90	4.50	4.30	5.15	3.90	5.30	4.45	3.75
13	4.70	8.80	7.80	6.80	4.90	4.40	4.20	5.00	3.85	5.30	4.40	4.00
14	4.30	8.30	8.00	6.70	4.80	4.70	4.00	4.70	4.10	5.10	4.50	4.05
15	4.50	8.00	7.90	6.20	4.70	4.60	3.90	4.50	4.00	5.00	4.50	4.25
16	4.50	7.10	7.70	5.90	4.60	4.30	4.10	4.35	3.60	4.80	4.40	4.90
17	4.30	6.80	7.90	5.80	4.60	4.50	4.20	4.20	3.70	4.75	4.35	7.90
18	4.20	7.00	7.60	5.60	4.50	4.40	3.90	4.00	3.75	4.60	4.25	7.35
19	4.40	7.50	7.30	5.60	4.40	4.40	3.80	3.80	3.80	4.55	4.30	6.70
20	4.20	7.30	7.00	5.50	4.30	4.40	4.65	4.05	3.85	4.25	4.25	6.35
21	4.50	7.20	6.60	5.20	4.60	4.30	6.00	3.95	4.05	4.30	4.30	6.65
22	8.50	7.20	6.60	5.20	4.40	4.70	6.60	4.05	3.75	4.45	4.20	8.60
23	6.80	6.80	6.10	5.10	4.30	4.50	6.00	4.10	3.60	4.40	4.20	8.40
24	6.30	6.50	5.90	5.10	4.10	4.30	5.70	4.10	3.70	4.45	4.05	7.55
25	5.80	6.80	6.00	5.00	4.20	4.30	5.50	3.95	3.65	4.45	4.15	7.30
26	5.60	7.00	6.00	4.90	4.50	4.30	5.30	3.95	3.85	4.40	4.25	6.90
27	5.90	10.60	5.90	5.00	4.60	4.20	4.95	3.95	4.20	4.30	4.60	6.65
28	5.70	9.00	5.90	5.10	5.30	4.20	4.85	3.95	4.60	5.85	4.50	6.00
29	5.30	.....	6.70	5.10	5.20	4.10	5.55	3.90	6.30	6.55	4.40	5.75
30	4.90	.....	6.70	6.20	5.00	4.30	5.45	3.90	6.00	6.00	4.25	5.90
31	4.90	.....	6.70	.....	4.70	.....	5.40	3.70	.....	5.80		5.60

Current-meter discharge measurements of Catskill Creek at South Cairo, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Oct. 10	2.58	23.3	Hollister and Schlecht.
Oct. 4	2.70	25.6	W. W. Schlecht.
Nov. 8	2.70	27.6	Do.
Aug. 19	2.70	39.6	Hollister and Place.
Sept. 23	2.74	35.6	W. W. Schlecht.
Nov. 9	2.75	42.3	Do.
July 4	2.75	60.9	Horton and Hollister.
Aug. 1	2.80	47.9	A. E. Place.
Oct. 22	2.82	54.2	W. W. Schlecht.
Sept. 7	2.92	68.8	A. E. Place.
Aug. 9	3.00	81.5	Do.
July 25	3.00	81.9	Do.
Sept. 2	3.00	87	Do.
Aug. 27	3.12	121.4	Do.
July 17	3.50	260.3	Pressey and Place.
July 20	3.60	307.5	A. E. Place.
June 13	2.69	40.6	W. W. Schlecht.
June 24	2.70	43.5	Do.
Aug. 27	2.74	39.4	H. K. Barrows.
Sept. 5	2.79	50	Do.
June 3	2.82	49.5	W. W. Schlecht.
May 23	2.83	51.1	Do.
Sept. 22	3.32	121	P. M. Churchill.
July 9	3.365	113.5	H. K. Barrows.
May 10	3.47	133	W. W. Schlecht.
Aug. 13	3.49	135	H. K. Barrows.
Nov. 7	3.80	235	F. H. Tillinghast.
Dec. 3	3.90	275	Do.
Oct. 10	3.92	242	P. M. Churchill.
Apr. 22	4.06	320.2	W. W. Schlecht.
Aug. 2	5.36	1,005	H. K. Barrows.
July 23	6.11	1,602	Do.
Apr. 11	6.86	2,312	W. W. Schlecht.
Mar. 13	8.66	5,483	Horton and Schlecht.

A measurement made February 27, 1902, with the stream obstructed by ice, showed the discharge 363 second-feet, gage height 4.72. The stream was frozen from bank to bank to a depth of 6 to 8 inches.

Current-meter discharge measurements of Esopus Creek at Kingston, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Aug. 5	3.60	39.9	A. E. Place.
July 22	3.80	64.2	Do.
July 18	4.10	144.9	Do.
July 5	4.32	148	Horton and Hollister.
July 19	4.40	172.7	A. E. Place.
Nov. 18	4.45	126.5	W. W. Schlecht.
Sept. 26	4.55	167.8	Do.
Do	4.55	150.4	Do.
Aug. 19	4.60	180.2	Hollister and Place.
Oct. 10	4.62	165.8	W. W. Schlecht.
Do	4.62	188.1	Geo. B. Hollister.
Oct. 8	4.70	178.2	W. W. Schlecht.
Nov. 1	4.74	184.3	Do.
Nov. 14	4.75	195.4	Do.
Sept. 21	4.78	209.3	Do.
Aug. 10	4.85	259.2	A. E. Place.
Nov. 26	5.06	244.7	W. W. Schlecht.
Oct. 3	5.26	329.4	Do.
Sept. 6	5.46	352.2	A. E. Place.
Aug. 29	5.50	364.3	Do.
Oct. 21	5.56	380.8	W. W. Schlecht.
Aug. 8	5.65	396.1	A. E. Place.
Sept. 4	6.11	554.3	Do.
Aug. 27	6.26	728.6	Do.
Oct. 16	6.64	785.2	W. W. Schlecht.
Dec. 19	8.35	1,472	Do.
Dec. 11	11.46	1,720.8	Do.
Dec. 30	12.15	3,989	Do.
1902.			
June 16	4.48	135.8	W. W. Schlecht.
Sept. 4	4.49	133	H. K. Barrows.
Aug. 21	4.94	191	Do.
June 26	5.02	225	W. W. Schlecht.
June 5	5.03	234.5	Do.
July 16	5.13	268.8	H. K. Barrows.
Nov. 22	5.45	272	F. H. Tillinghast.
July 9	5.81	450.4	Barrows and Schlecht.
May 14	5.83	422	W. W. Schlecht.
Sept. 23	5.87	449	P. M. Churchill.

Current-meter discharge measurements of Esopus Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1902.	*Feet.*	*Second-feet.*	
Nov. 11	6	416	F. H. Tillinghast.
Aug. 12	6.28	550	H. K. Barrows.
May 24	6.38	[a] 274	W. W. Schlecht.
June 5	6.41	[a] 272	Do.
Nov. 5	6.56	594	F. H. Tillinghast.
Apr. 23	6.94	828.3	W. W. Schlecht.
May 14	7.14	[a] 508	Do.
July 30	7.65	1,155	H. K. Barrows.
July 24	8.11	1,348	Do.
Oct. 4	9.32	1,890	P. M. Churchill.
Mar. 12	9.90	2,843	Horton and Schlecht.
Apr. 30	10.28	2,813	W. W. Schlecht.
Apr. 10	13.37	5,021	Do.
Mar. 1	20.38	[b] 12,620	Do.

[a] Measured at Glasgow Bridge, Glen Eyrie.
[b] Large quantities of floating ice in the stream. Surface velocities used.

The following measurements were also made during the period of ice obstruction by W. W. Schlecht:

February 20: Gage height, 5.38; discharge, 245 second-feet; river partly frozen over. February 15: Gage height, 5.60; discharge, 557 second-feet; river mostly frozen over. February 7: Gage height, 6.83; discharge, 530 second-feet; river partly frozen. September 29, 1.30 p. m., the stream attained a flood stage, giving a reading of 25.25 on the gage.

Current-meter discharge measurements of Rondout Creek at Rosendale, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
July 18	6.30	118.2	A. E. Place.
Aug. 6	6.40	99.4	Do.
Nov. 7	6.42	138.2	W. W. Schlecht
Sept. 24	6.45	139.6	Do.
Oct. 11	6.47	163.2	Do.
Oct. 11	6.47	201.8	G. B. Hollister.
Nov. 16	6.55	183	W. W. Schlecht.
July 6	6.55	319	Horton and Hollister.
Aug. 15	6.55	225.4	A. E. Place.
Oct. 7	6.60	217.5	W. W. Schlecht.

Current-meter discharge measurements of Rondout Creek, etc.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Sept 7	6.90	426.7	A. E. Place.
Aug. 20	6.94	526.4	Hollister and Place.
Oct. 18	7.03	509.9	W. W. Schlecht.
Aug. 28	7.15	644.6	A. E. Place.
Aug. 8	7.50	745.4	Do.
Sept. 4	7.56	836.1	Do.
Dec. 21	7.60	772	W. W. Schlecht.[a]
Sept. 3	7.80	1,200	A. E. Place.
Dec. 12	8	1,490.8	W. W. Schlecht.
Nov. 26	7.21	675.4	Do.
Dec. 30	11.95	5,353	Do.[a]
1902.			
Sept. 25	6.31	167	B. M. Churchill.
July 15	6.33	141.9	H. K. Barrows.
July 18	6.33	137.2	Do.
Aug. 29	6.33	145	Do.
June 6	6.38	163	W. W. Schlecht.
June 20	6.42	166	Do.
Nov. 21	6.55	283.4	F. H. Tillinghast.
Dec. 2	6.70	367	Do.
Apr. 28	6.83	382	W. W. Schlecht.
May 12	6.855	421	Do.
Nov. 4	7.00	570	F. H. Tillinghast.
Aug. 7	7.39	838	H. K. Barrows.
July 29	7.40	888	Do.
Mar. 21	8.07	1,529	W. W. Schlecht.
Mar. 1	17.60	13,936	Do.
Apr. 11	11.78	5,666	Do.

[a] Stream somewhat obstructed by shore ice.

Additional measurements were made by W. W. Schlecht while the river was frozen over, as follows:

February 18, gage height, 7.70; discharge, 342 second-feet. The river was frozen over from bank to bank and slush had collected below the ice.

February 26, gage height, 8.13; discharge, 543 second-feet. Slush below the ice made an unsatisfactory record.

February 26, gage height, 8.43; discharge, 684 second-feet. Ice covered the river from bank to bank and slush had collected underneath.

The Delaware and Hudson Canal has been abandoned in New York State, with the exception of the portion from High Falls feeder on Rondout Creek to tide water, below Eddyville. The gaging station at Rosendale is situated opposite the canal level between locks 6 and 7. The water supply of this level is drawn entirely from Rondout Creek. In order to determine the amount of this diversion during the season of canal navigation, usually from April 1 to December 10, a record has been kept at lock No. 6, or Creek Locks, at the lower end of the Rosendale level. The record includes overflow at by-pass weir, water used for lockage, and flow through paddles in miter gates. There is also a small amount of leakage in the lock walls and gates which has not been determined. The flow in the canal at lock No. 6 added to the flow at the Rosendale station will give the total actual run-off from Rondout Creek above Rosendale. The following tables show the mean monthly and estimated daily diversion during the canal season of 1902. The estimated flow in the canal as recorded in 1901 is as follows:

	Second-feet.
October, 1901	20
November 21, 1901	19

Mean monthly diversion in second-feet to Delaware and Hudson Canal, lock No. 6, near Rosendale, in 1902.

	Second-feet
March [a]	15.70
April	22.45
May	29.98
June	23.67
July	23.78
August	24.33
September	23.99
October	22.23

Current-meter measurements of Wallkill River at New Paltz, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
1901.	*Feet.*	*Second-feet.*	
Nov. 9	5.94	178	W. W. Schlecht.
July 23	5.20	306	A. E. Place.
Oct. 11	6.30	340	W. W. Schlecht.
Oct. 11	6.30	355	Geo. B. Hollister.
Oct. 24	6.33	333	W. W. Schlecht
Oct. 9	6.48	398	Do.
Nov. 16	6.50	402	Do.
July 7	7.19	824	Horton and Hollister.
July 8	7.25	842	Do.

[a] March 23 to 31, inclusive.

Current-meter measurements of Wallkill River at New Paltz, N. Y.—Continued.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
Oct. 1	7.36	896	W. W. Schlecht.
Nov. 27	7.52	1,022	Do.
Sept. 19	7.73	1,076	Horton, Place, and Schlecht.
Aug. 13	7.85	1,038	A. E. Place.
July 19	8.25	1,243	Do.
Sept. 5	8.90	1,676	Do.
Aug. 31	9.07	1,917	Do.
Aug. 20	10.00	2,729	Hollister and Place.
Aug. 28	10.60	2,982	A. E. Place.
Dec. 11	11.50	3,040	W. W. Schlecht.[a]
Dec. 19	13.70	3,277	Do.[a]
Aug. 7	14.85	7,365	A. E. Place.
1902.			
July 17	5.70	124.3	H. K. Barrows.
Aug. 28	5.86	169	Do.
Sept. 18	5.96	209.5	Barrows and Churchill.
June 19	6.18	295	W. W. Schlecht.
May 21	6.33	344	Do.
June 6	6.40	381	Do.
Nov. 18	6.62	550	F. H. Tillinghast
May 13	6.68	506	W. W. Schlecht.
Aug. 15	6.72	518	H. K. Barrows.
Dec. 2	6.80	626	F. H. Tillinghast.
Apr. 26	6.92	[b] 680	W. W. Schlecht.
Feb. 24	7.33	288	Do.
July 29	7.49	942	H. K. Barrows.
Apr. 21	7.57	[c] 1,028	W. W. Schlecht
Feb. 10	7.78	597	Do.
Nov. 4	7.95	1,165	F. H. Tillinghast.
Aug. 6	7.98	1,150	H. K. Barrows.
May 1	10.264	2,623	W. W. Schlecht.
Apr. 9	13.21	5,354	Do.
Mar. 11	15.93	7,140	Do.

[a] Stream obstructed by ice causing backwater.
[b] Measured through ice 1 foot 6 inches to 2 feet 6 inches in thickness.
[c] Measured through ice 1 foot to 2 feet in thickness.

Current meter measurements of Fishkill Creek, at Glenham, Dutchess County, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
July 24	3.60	60	A. E. Place.
Oct. 12	3.80	97	Geo. B. Hollister.
Nov. 11	3.85	82	W. W. Schlecht.
Aug. 15	3.85	110	A. E. Place.
Sept. 27	3.86	90	W. W. Schlecht.
July 20	3.90	135	A. E. Place.
July 8	3.92	147	Horton and Hollister.
Nov. 20	3.95	114	W. W. Schlecht.
Oct. 5	3.98	126	Do.
Oct. 15	4.05	137	Do.
Sept. 6	4.15	193	A. E. Place.
Sept. 18	4.22	229	Do.
Dec. 24	4.52	315	W. W. Schlecht.
Aug. 21	4.56	342	A. E. Place.
Aug. 30	4.60	325	Do.
Dec. 13	4.62	375	W. W. Schlecht.
Oct. 15	5.10	579	Do.
Dec. 31	7.43	2,210	Do.[a]
1902.			
Aug. 26	3.04	48.5	H. K. Barrows.
July 14	3.18	64.4	Do.
Aug. 11	3.51	115	Do.
Oct. 11	3.71	155	P. M. Churchill.
June 2	3.785	132.3	W. W. Schlecht.
July 28	3.90	200	H. K. Barrows.
June 17	4.00	212.5	W. W. Schlecht.
Nov. 8	4.00	233	F. H. Tillinghast.
Apr. 25	4.03	[b]152.4	W. W. Schlecht.
May 6	4.46	349.5	Do.
Feb. 11	4.87	[c]202.5	Do.
Oct. 30	4.97	697.7	C. C. Covert.
Apr. 12	5.30	772.6	W. W. Schlecht.
Mar. 5	5.79	1,129	Do.

[a] Surface velocity used.

[b] Probably incorrect.

[c] Ice along banks at gaging station, frozen from bank to bank 90 yards below station 2 to 9 inches thick.

Current-meter discharge measurements of Tenmile River at Tabor's bridge, below Dover Plains, N. Y.

Date.	Gage height.	Discharge.	Hydrographer.
	Feet.	*Second-feet.*	
1901.			
Sept. 16	5.27	245.4	A. E. Place.
Sept. 28	4.36	70.3	W. W. Schlecht.
Nov. 11	4.75	121.5	Do.
Nov. 22	4.76	123.4	Do.
Nov. 22	4.76	120.9	Do.
Nov. 6	4.88	140.1	Do.
Oct. 26	5.01	187.6	Do.
Dec. 27	6.54	554	Do.
Oct. 15	7.19	692.8	Do.
Dec. 17	8.41	1,213.4	Do.
1902.			
Sept. 2	3.95	63	H. K. Barrows.
Aug. 19	4.28	100	Do.
June 10	4.45	[a] 158	W. W. Schlecht
Feb. 13	4.67	179	Do.
Aug. 4	4.69	184.8	H. K. Barrows.
Nov. 28	4.80	211.5	F. H. Tillinghast.
Nov. 14	4.87	211	Do.
May 15	4.88	230	W. W. Schlecht.
June 30	4.92	249	Do.
May 28	5.50	380	Do.
Oct. 2	5.80	443	P. M. Churchill.
Apr. 15	6.13	526	W. W. Schlecht.
Apr. 7	6.18	558	Do.
May 2	6.46	640	Do.
July 21	7.18	821	H. K. Barrows.
Mar. 3	10.41	2,386	W. W. Schlecht.

[a] River nearly covered with ice from bank to bank and 1½ to 2½ inches thick.

Current-meter discharge measurements of Housatonic River at Gaylordsville, Conn.

Date.	Gage height.	Discharge.	Hydrographer.
1900.	*Feet.*	*Second-feet.*	
Oct. 20	3	303	E. G. Paul.
Oct. 24	3.10	370	Do.
Aug. 10	3.25	422	Do.
Aug. 9	3.30	450	Do.
1901.			
Aug. 3	3.50	549.5	A. E. Place.
Sept. 28	3.78	700.8	W. W. Schlecht.
Sept. 13	4	911.7	A. E. Place.
Oct. 29	4.05	951	W. W. Schlecht.
Nov. 23	4.11	965.4	Do.
Nov. 13	4.82	1,863.7	Do.
Dec. 28	5.16	2,250	Do.
1902.			
Sept. 8	3.45	543	H. K. Barrows.
Sept. 19	3.75	640	Barrows and Churchill.
Aug. 20	3.95	835	H. K. Barrows.
Aug. 5	4.28	983	Do.
July 11	4.30	1,159	Do.
Nov. 29	4.40	1,281	F. H. Tillinghast.
June 23	4.46	1,177	W. W. Schlecht.
Nov. 15	4.50	1,356	F. H. Tillinghast.
Oct. 3	5.35	2,133	P. M. Churchill.
May 3	6.10	4,459	W. W. Schlecht.
July 22	6.68	5,119	H. K. Barrows.
Mar. 18	7.63	8,259	W. W. Schlecht.
Mar. 4	9.9[illegible]	13,601	Do.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., October 1, 1902.

SIR: I have the honor to transmit herewith a manuscript by Waldemar Lindgren, geologist of this Survey, with the request that it be published in the series of Water-Supply and Irrigation Papers. This manuscript relates to the water supply of Molokai, one of the Hawaiian Islands. It was prepared from the results of an investigation made unofficially by Mr. Lindgren in 1900. The observations made at that time and the conclusions drawn from them have such general interest, as showing the possibilities and limitations of one of the group of islands, that it is desirable to make them available to the public. Of especial interest are Mr. Lindgren's notes on the gradual decrease of the forested area, the probable effect of grazing, and the intimate relations of these to the available water supply.

The problems of water conservation are here shown to be rather difficult and involved, but are similar in many respects to those of the arid West, the solution being found in combined systems of storage, water-power development, use of the power in pumping, the construction of wells, collecting tunnels, and the economical employment of various devices for lifting water. Opportunity is thus offered for the exercise of skill and mature judgment by the geologist, hydrographer, and civil and mechanical engineer.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director of United States Geological Survey.

KALUAKOI
PUNAKOU
PALAU
KIPU
MANO WAINUI
PALAU
HOOLEHUA
NAIWA
KALAMAULA
KAUNAKAKAI
KAMILOLOA
MAKOLELAU
KAMALO
KALAELOA
KOLU
HALE
Puu Ka Pele
Puu Ahanaiole
Puu Kahanui
Puu Papai
Puu Ali'i
Puu Kolu
Puu Wi
Puu Hinahina
Puu Kaiaiki
Puu Kaiaiki
Puu Kaiaiki

THE WATER RESOURCES OF MOLOKAI, HAWAIIAN ISLANDS.

By WALDEMAR LINDGREN.

INTRODUCTION.

Molokai is the fifth in size of the Hawaiian Islands, and is situated between Oahu and Maui. Oahu is 23 miles distant, and from higher points Diamond Head is in plain sight on clear days. From Maui it is divided by a sound only 8 miles wide. Not much farther to the south rises the dry, rocky coast of Lanai, a still smaller island, chiefly used as a sheep range. Molokai is a narrow strip of land, extending 39 miles from east to west and having an average width of a little less than 7 miles. The area is 261 square miles. The population in 1900 numbered 2,500. The island stands on the submarine plateau from which the whole northern group rises, so that no extreme depths are found in the channel between Oahu and Molokai, nor between Molokai and Maui. Coral reefs fringe nearly the whole south coast of Molokai, but few occur on the north shore. This north shore is the windward side, receiving the full impact of the trade winds and a great amount of moisture. In strong contrast to this the south shore is extremely dry.

Molokai is outside of the ordinary course of travel. No description of the island has ever been published, as far as I know, excepting somewhat stereotyped references to the leper settlement in books of travel. The more easily accessible portions are not attractive, and the northeast coast, which is characterized by wonderful scenery, is hardly ever visited by travelers.

TOPOGRAPHY.[a]

Three natural divisions may be recognized in the relief of the land: (1) The west end, or Kaluakoi; (2) the low gap separating Kaluakoi from the principal mountain range; and (3) the eastern range.

[a] The Hawaiians do not ordinarily designate directions by the four points of the compass. They have instead two very expressive terms: *Mauka*, meaning upward, toward the higher parts of the island, and *Makai*, meaning the opposite, or toward the sea. It also seems that they do not usually designate the water courses by special names, but instead apply to them the name of the subdivision of land through which they happen to flow. As will be seen from the map, each subdivision has its own name.

The west end, or Kaluakoi, comprises about 55 square miles. This area consists of a broad, bare, and grassy ridge, beginning at the light-house at the southwestern extremity of the island and culminating, with an elevation of 1,382 feet, in the round-topped hill of Mauna Loa. Rocky and abrupt ravines lead southward from this backbone to the sea, while long gulches with gentler grade, and separated by broad ridges, reach the north shore. Here a steep cliff has been formed by the action of the waves (Pl. II, *A*). A sharp slope, or pali, a few hundred feet high, runs northward from Mauna Loa, dividing the west end from the low gap.

A low gap separates Kaluakoi from the principal mountain range of the island. The lowest point of this divide is 450 feet above sea level. Gently rolling smooth surfaces characterize this broad gap or saddle; on the south it is cut by shallow gulches and slopes gradually to the sea, while on the north shore the surf has sculptured a low sea cliff gradually merging into the great precipice or pali which from here on follows the northern coast. This gap contains the best and most extensive sugar-cane lands on the island, the total area being about 14,000 acres of deep red, extremely fertile soil. This area is sharply separated from the west end by Mauna Loa Creek on the south side of the island and by the above-mentioned low pali on the north. Eastward the rolling country gradually rises to the plateau of the main mountains of the island.

The eastern range comprises the largest part of the island. This may be briefly described as a segment of a circle, the chord of which extends east and west and has a length of about 25 miles. The line dividing the north-south drainage is, roughly speaking, parallel to the curve of the southern coast. The mountains culminate almost in the center of the island in the peak of Kamakou, which attains an elevation of nearly 5,000 feet. The south slope is gradual, and is furrowed by a great number of straight and narrow, though often deep, ravines (Pl. II, *B*, and Pl. III, *A*). The north slope is abrupt, in places precipitous, and is marked by five most extraordinary recesses or alcoves, cut in the face of the scarp. This great precipice and these alcoves are the most remarkable feature of the island's topography. North of the great gap of the island the great pali has a height of only a few hundred feet, which increases to 900 feet north of Molokai Home ranch and reaches 1,500 feet, where the trail to the leper settlement crosses it. From this point eastward the great precipice is much higher and from Waikolu to Wailau attains elevations of from 2,500 to 3,500 feet; then it gradually decreases again to Halawa, where it ends near the eastern point of the island, having there an elevation of 850 feet. The character of this pali may be seen from Pl. III, *B*, and IV, *A*. When of moderate height, i. e., up to 1,500 feet, it forms practically one continuous slope of from 50° to 70°, with practically no level land below. The surf beats directly against the foot of the escarpment.

A. SOUTH COAST OF MOLOKAI AT KOLO WINDMILL, WEST END OF ISLAND. LOOKING WEST.

Showing seacliff and successive basalt flows sloping down toward the coast.

B. MOUTH OF KAWELA GULCH, SOUTH COAST OF MOLOKAI

Showing bowlder-filled creek bed and steep side slopes cut in basalt.

At the mouth of the Wailau Valley, and wherever it attains great height, there is usually a vertical or practically vertical cliff from a few hundred to a thousand feet high. Above this a slightly more gradual slope prevails, but for 2,000 feet above sea level the average declivity is often about 70°. Above this the slope flattens to something like 45°. The precipitous rock walls are channeled by a great number of parallel grooves cut by the rain water, and wherever the slopes are not vertical the dark colored rock is covered by a mantle of bright green vegetation. Only in one place is there is any important land mass projecting northward at the foot of the pali. That is the peninsula of the leper settlement, Kalaupapa, a rocky and dry peninsula 2 miles wide and 2 miles long, its highest point rising only a few hundred feet above the sea and marked by the crater of a small extinct volcano.

Next to the great pali itself the most remarkable features of the northern coast are the deep recesses or alcoves which erosion has carved into it, alcoves with exceedingly steep, sometimes perpendicular slopes, of wonderful beauty and grandeur, over the edges of which the waters of the upper drainage basins fall in numberless cascades, increasing to magnificent waterfalls during the rainy season.

West of Waikolu Valley the main divide of the island is close to the northern shore, but here it turns southeasterly and curving follows approximately the central line of the island. The three western alcoves, Waihanau, Waialeia, and Waikolu, have as yet not cut back very far and are therefore most characteristic of their type. All three have a shorter upper high level drainage consisting of small canyons in the high plateau, 200 to 400 feet deep, connected by cascades with the lower straight and deep canyons, 2 to 3 miles in length. The even verdure-clad side slopes descend at angles of from 40° to 60° to the water course in the bottom. At the head of the canyon the declivities become much more precipitous and form an amphitheater in strong contrast to the rolling or level summit plateau. At the head of the alcove and at various places from its sides the waterfalls descend like narrow white threads for 2,000 feet into the black depths of the chasm. Deep grooves and holes have been worn into the rock by the falls, so that in places they disappear altogether from view. More extensive and branching are the two principal streams of the island, Pelekunu and Wailau. They occupy watersheds of 4 or 5 square miles, but they, too, are surrounded by the same precipices, especially near the headwaters at the main divide. They are clearly of the same origin as the smaller alcoves, but a stronger erosive action has widened the valleys and extended their canyons. The grades of the streams are heavy throughout, and except at the north of the canyon there are practically no bottom lands. Pl. IV, *B*, shows the mouth of Wailau, with the broad, almost U-shaped form at the debouchure, and the furrowed slopes descending from the high plateau of the island.

The Halawa, another of the permanent streams of the island, flows in an easterly direction, heading in the swamps of the plateau east of Wailau, descending in a great waterfall to the lower alcove or canyon, and debouching near the extreme eastern end of the island.

From the headwaters of Waihanau to Kamakou, the highest peak on the islands, the summit region consists of gently sloping or hilly plateaus, generally swampy and cut by sharply incised ravines. The elevation of this plateau is only 2,000 feet south of the leper settlement but increases to 3,500 south of Waikolu and to over 4,000 between Waikolu and Pelekunu. Parts of the plateau project between the canyons, contrasting sharply against the precipices of alcoves and pali. From Kamakou for several miles eastward there is no central plateau, or only fragments of it. The drainage from north and south has cut in deeper and left only a sharp and jagged ridge. But between Wailau and Halawa there are again several square miles of the upper surface left.

The south slope of the island is very different from the northern. South of the divide the plateau gradually changes to a sharper slope, over which the water courses find their way in small cascades and falls. This decided slope is most accentuated on the Kawela, but is noticeable all along the south side of the island. The lower declivities, up to an elevation of 800 feet above the sea, are again gentle, having an inclination of from 5° to 8°, and a fringe of narrow flats follows the coast line. Instead of a few great canyons, some forty or fifty gulches and ravines form the drainage ways of the southern slope. All of these have the same characteristics, namely, a straight course, small drainage area, sharp grades, especially in their middle portion, and very abruptly incised sides, rarely, however, cut more than 400 or 500 feet below the slope of the surface. These conditions are the natural result of a comparatively recently established drainage system over the smooth sides of a volcanic cone. East from Kawela the straight, steep gulches are even more numerous than in the western part. Pl. III, A, shows the great Kamalo Gulch back of the plantation of the same name. It illustrates well the V-shaped form of the canyons as well as the partially preserved surface of the old lava cone. On the whole, the streams draining north are permanent, while those draining south carry water only during the rainy season, and then intermittently.

GEOLOGY.

Like the other islands of the Hawaiian group, Molokai is almost entirely of igneous origin. It is a volcanic cone built up in the middle of the ocean by a great number of superimposed basaltic flows. The island is, in fact, like Maui, formed by two volcanoes, and these two cones are separated by a low gap on which secular disintegration has reduced the basalt to a deep red soil.

A. KAMALO GULCH, SOUTH COAST OF MOLOKAI.

Showing parts of surface of volcanic cone, deeply dissected by gulches, débris fans at mouth of gulches, and coral reef below shallow water near shore.

B. NORTH COAST OF MOLOKAI, LOOKING WEST FROM THE LANDING AT WAILAU.

Showing fault scarp along northern coast, horizontal basalt flows near base of cliff, and peninsula of leper settlement in the distance.

The west end forms one, separate and complete, though comparatively low cone. Partly obliterated craters are still visible near the summit, between Mauna Loa, Kaana, and Amikopala. The cone is not very regular, and secondary centers of eruption were probably located near the southwest and northwest corners of the island. The steep pali running north from Mauna Loa to the coast indicates a dislocation along which the east side has dropped a few hundred feet.

The main or eastern part of the island is not of so simple a structure. It represents one part, and probably the smaller part, of a large volcano, the northern part having dropped down along a great break or dislocation to a depth of from a few hundred to 3,000 or even 4,000 feet. Thus, the great northern pali, described in the previous pages, is really a break or a fault line, which split the volcano in two. The evidence of this is clear and convincing. The slopes of the lava flows are everywhere to the south, from 4° to 13°; even in the cliffs of the north coast the same inclination is observed. This, in conjunction with the form of the island, shows that a part of the volcano has been removed. Neither wave action nor erosion by running water could possibly have produced such an escarpment as that of the great pali, reaching 3,000 feet in height. The work of erosion on this cliff is shown plainly enough in the great alcoves cut by the water courses and described in previous pages. This erosion is still cutting southward and the divide is no doubt steadily migrating in that direction.

Dana, I believe, was the first to insist that the outlines of these islands have been to some degree determined by dislocations; and in his Characteristics of Volcanoes[a] is the only reference to Molokai which I have found in geological literature. It is as follows:

> Molokai was once, as its lava streams prove, a doublet of volcanoes like Maui, but it has been shaved down to a strip of land. The eastern part has an alcoved precipice facing the north, which rises to a height of 2,500 feet above the sea. Thus, such precipices are rather the rule in the Hawaiian group, and if seashore erosion is not the origin, fractures and subsidence must be.

Dana's view of the causes of the abrupt topography on the eastern coast of Oahu has been disputed by C. H. Hitchcock,[b] who believes that the action of erosion is sufficient to account for it. There is no doubt that deep canyons with very steep walls and almost perpendicular precipices near the heads of the water courses are most characteristic among the forms of erosion on the windward side of the island, and that, therefore, some caution must be exercised in discriminating precipices of erosion from those of fault scarps. However, in the case of Molokai, Dana's statement is undoubtedly true; the great pali is most certainly a fault scarp of magnificent size.

The low peninsula of Kalaupapa, the only land of importance at the foot of the cliff, seems to be a part of this sunken area, still above

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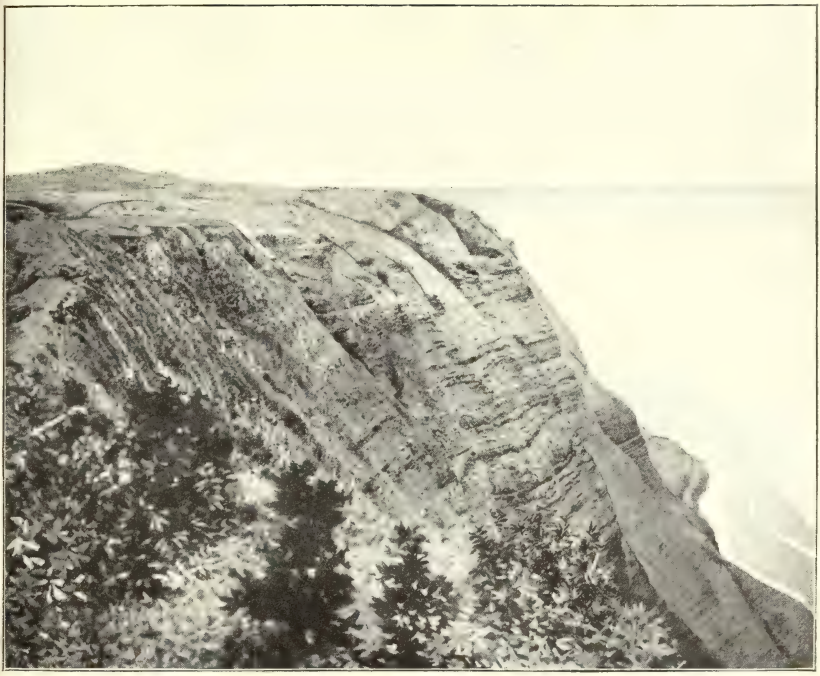
[a] 1890, p. 290.

[b] Bull. Geol. Soc. Am., Vol. II, 1899, p. 23.

water. A crater and several lava streams still remain on this peninsula and are better preserved than most of those on the south side. The gently sloping summit plateau does not contain, as far as known, any remaining craters, but it is covered by extremely thick vegetation and few parts of it are accessible. Numerous smaller subcraters or parasitic cones remain, imperfectly preserved, on the long southern slope of the island. They generally have flat tops—the crater funnels being filled in—and intense red or yellow colors due to thermal action on the lavas. Such are Middle Hill, Puu, Luahine, Kakalahale, Maninibolo, and many others.

Similar in general to the other islands, the rocks of Molokai consist almost exclusively of dark basaltic, fine-grained lavas of more or less porous structure. The flows are thin, and range from a few feet up to 50 feet in thickness, but rarely exceed the latter limit. Laterally the flows are ordinarily not continuous over a great distance, hence exposures or wells only a few hundred feet apart may show very differing sections. Harder, more compact lavas alternate with exceedingly porous, loose breccias or agglomerates. The deepest parts of the gulches, the well sections, and the palis at Waikolu, Pelekunu, and Wailau all show the same structure, clearly indicating that the island has been built up by rapidly succeeding thin lava flows. The probability is very strong that this same structure and the same kinds of rocks continue down to a depth of several thousand feet. No petrographic study of the rocks has been undertaken, but a few thin sections make it evident that the rocks chiefly consist of normal feldspar basalt, somewhat glassy, and with olivine, occasionally also containing phenocrysts of soda-lime feldspars. Thus far the only kinds of rocks recognized by petrographers in the Hawaiian Islands are of the type of feldspar basalts, with occasional occurrences of nepheline-basalts or nepheline-melilite-basalts. In exploring the headwaters of Wailau, in the very heart of the dissected volcano of Molokai, however, an interesting occurrence of coarse-grained intrusive rock was found. Crossing the gap north of Mapulehu one descends over a precipice leading down to the valley of Wailau over a difficult and almost dangerous trail, which finally follows the bed of the east fork down to its junction with the larger west fork. Down to the junction only ordinary basaltic rocks are met with, but the west fork is full of heavy bowlders of a dark-green, coarse, granular rock, manifestly different from anything formerly described from the islands. The rock was not found in place, nor was the west fork followed up to its source, where these bowlders must come from. Indeed, in the thick tropical jungle which covers the whole watershed of Wailau, this is a very serious undertaking, but there must be a large mass of this rock in place, too large to have been carried up by the eruption of the lavas, and therefore it is most probably an intrusive body injected into the volcanic masses and there consolidated.



A. NORTH COAST OF MOLOKAI, LOOKING WEST FROM SUMMIT OF TRAIL TO LEPER SETTLEMENT.

Showing summit plateau and fault scarp, exposing a great number of basalt flows. Elevation 1,600 feet above sea level.

B. NORTH COAST OF MOLOKAI, MOUTH OF WAILAU VALLEY, LOOKING EAST.

Showing fault scarp 3,000 feet high and alcove type of eroded valleys.

Upon examination in thin section the rock presents a normal coarse granular structure, without glass, and consists of broad laminæ of a soda-lime feldspar not far from anorthite. Between these lie grains of a pale-violet, slightly pleochroic augite, with which are associated numerous grains of an iron ore. In addition, there are grains of olivine, slightly serpentinized, and in much smaller quantity than the augite. The rock is therefore a very coarse olivine-diabase.

Mr. Monroe, the superintendent of Molokai ranch, gave me a small specimen of a somewhat similar but slightly more decomposed rock which he had broken from a large bowlder in one of the principal streams on Kauai, the most northerly of the large Hawaiian islands. This proved to be very similar to the rock just described, being a coarse-grained diabase. A remarkable feature of the rock from Kauai is the deep purplish color of the augite. It is only slightly pleochroic.

These two coarse-grained rocks are the only occurrences of the kind thus far found in the Hawaiian Islands.

Unlike Oahu, Molokai has no extensive flats of sediment soil underlain by coral and tuffs. The sediments are chiefly confined to small strips and areas of less than 200 acres, and occur at intervals, especially near the mouths of the gulches along the south coast from Palaau to Pukoo. The soil is ordinarily, at no great depth, underlain by basaltic lava. Rarely is there a thin layer of coral rock between the soil and the lava rock.

The gap or the space between the two volcanoes which make up the island is of a rolling character and is covered by soil. A considerable part of this gap is covered by sediment soil, fine red soil, and well-rolled gravel, mixed. This sediment is doubtless chiefly carried down from the east side, and antedates the time when the volcano was split in two and the northern half engulfed in the sea.

As may be expected, the extremely steep gulches from Kawela eastward have brought down big fields of bowlders from the slopes above (Pl. II, *B*).

CORAL REEFS.

A coral reef from one-half to 1 mile wide fringes practically the whole southern coast of the island. The parts adjacent to the main gulches are gradually being filled up by mud. Thus, the island is gradually growing out in this direction. Seen from a high point, the reddish mud flats skirting the shore contrast strongly against the brilliant emerald green of the reef; and beyond this is the dark violet-blue color of the deep sea.

Small amounts of coral rock, indicating a former higher water level, are found all along the southern coast; usually these only reach 25 feet above water level, though in one place—near Puu Maninibolo—

this old coral reef extends up to 130 feet above the sea. The submergence was evidently of short duration.

The coral sand carried up by the waves forms a very narrow fringe all along the southern coast. A large dune wall of coral sand, about 12 feet high, skirts the western coast at Papohaku flats.

Though the coral reefs on the northern or windward side are not extensive, a very large area of dune sand occurs north of the gap and extends for several miles westward, having a width as great as 4,000 feet. The locality is particularly exposed to the full force of the trade winds, and the sand is carried up to the top of a 500-foot hill, where it accumulates in dunes which reach a thickness of 20 feet. Westward the sands finally reach the two creeks emptying near Papohaku, from which repositories the winter floods carry them down to the sea. Part of these dunes are consolidated to hard sandstones. In some of these are seen peculiar footprints which are similar to, and yet somewhat different from, the imprint of a human foot. There are also many obviously recent inscriptions, etc., and, as the Hawaiians are not altogether averse to a practical joke, the real character of these footprints may as yet be left an open question.

CLIMATE.

In regard to temperature, the island possesses the same equable climate as that enjoyed by the others of the same group; frost probably never occurs, even at the highest elevations. The trade winds are strong, especially during the winter months and on the northern coast. During long periods it is impossible to effect a landing at the settlements of Wailau and Pelekunu. Even along the south coast the winds are usually strong in the afternoon, and over the bare west end, or Kaluakoi, and over the gap the breezes sweep without hindrance. There is in general a wet season, extending from October until the end of May, and a dry season including the summer months. On the whole, the west end, the gap, and the south shore as far as Kamalo are included in the arid zone of the island, while the whole northeasterly part may be counted as one of abundant precipitation. All points over 2,500 feet in elevation receive an abundant rainfall. Most of this falls in the winter, but showers occur at intervals all through the summer. Accurate data regarding rainfall extending over any considerable period are not obtainable.

Data collected by Dr. Morritz at Mapulehu, on the southern coast and the eastern part of the island, from 1894 to July, 1899, show an average annual precipitation of 34 inches with but little variation and no apparent decrease. The maximum precipitation is usually in December, with as much as 6 inches, while the minimum monthly precipitation in the summer is 1 inch.

At Kaunakakai no records have been kept except for a month or

two in 1900, but it is apparent that the rainfall decreases rapidly west of Mapulehu. The probable annual rainfall at Kaunakakai does not exceed 10 inches, thus indicating a very dry climate. About 2 inches are said to have fallen in January, 1900. About 0.6 of an inch fell April 24, 1900, while since that time, up to July 1, 1900, there were only slight showers at great intervals; a little rain fell June 23, and again a little on June 27 and 28.

There are indications that the rainfall at Palaau, on the south side of the gap, is somewhat larger than at Kaunakakai, and this is, indeed, to be expected, for its position is more open to the northeasterly trade winds. On the north side of the gap precipitation is still further increased, as is indicated by the strong growth of grass, remaining green up to June 1.

At Molokai ranch, at an elevation of 850 feet and only a short distance from the gap, records have been kept by Messrs. Schleifer and Monroe since January, 1899, with the following results:

Rainfall at Molokai ranch.

Month.	1899.	1900.
	Inches.	*Inches.*
January	2	2.69
February	3.75	4.14
March	3	1.36
April	1.90	5.30
May	.50	.83
June	([a])	2
July	([a])	...
August	([a])	...
September	([a])	...
October	1.23	...
November	1.29	...
December	1.71	...
Total recorded	15.38	...

[a] No record.

The figures for 1898–99 are incomplete. The season was one of great deficiency in rainfall, and this dry winter was followed by an exceptionally dry summer. The total for the rainy season 1899–1900 is 20.55 inches, indicating an annual rainfall at this place of about 22 inches.

At Meyer's ranch, at an elevation of 1,400 feet, about 2 miles northeast of Molokai ranch, records were kept for some time by Mr. R. W. Meyer, but I have only been able to obtain those of 1891. This year was, as the records show, an exceptionally dry one on Oahu and Maui. At Honolulu 23 inches fell that year against a normal rainfall of 38 inches. It is believed that the latter figure represents the normal rainfall at Meyer's ranch.

Precipitation in 1891 at Meyer's ranch.

	Inches.
January	7.65
February	3.28
March	.36
April	4.35
May	1.63
June	None.
July	None.
August	None.
September	None.
October	4.40
November	.20
December	1.26
Total	23.13

Above an elevation of 2,000 feet in this part of the island almost daily showers occurred from April 1 to May 28, 1900, and this is probably the normal condition during the winter months. Dry and warm weather prevailed from May 28 to June 8, when light showers fell. Again, on June 23, 26, and 27 there was a considerable amount of rainfall.

Regarding the quantity of rainfall in the mountains there is scant information. The annual precipitation probably reaches 100 inches at elevations of 3,000 and 4,000 feet and is not far from this amount over a considerable area on the north slope on the headwaters of Waikolu, Pelekunu, and Wailau.

It has been asserted that the rainfall on Molokai is decreasing. As far as the data go there is nothing to prove such an assertion. It is no doubt true that the island formerly supported a much denser population; this is indicated, for instance, by many old garden patches at streams which are now dry or carry water only intermittently. All this is, however, most probably directly chargeable to the destruction of the forests and the following irregularity or disappearance of the water supply.

SOILS.

The soils of Molokai are similar to those of the other islands of the Hawaiian group and are usually of great fertility. They may be divided into residual and sedimentary soils.

The residual soils result from the gradual decomposition of the basaltic lavas and are usually deep red, very rich in iron and in substances necessary for plant growth.

The sedimentary soils are partly of a deep-red color, partly dark brown, and not very different in character from the residual soils; they consist, in fact, of the same substance merely transported and redeposited. In a few places along the immediate coast line are small areas covered by coral sand, consisting largely of carbonate of lime, usually more or less mixed with detritus from the hills.

The west end of the island contains a very great amount of good, smooth land, with excellent soil. In fact, the larger part of Kaluakoi is of this character, excepting the southern slope of the long ridge extending from Mauna Loa to the light-house, the extreme northern and western portion, and the steep slope extending from Mauna Loa northward to the sea. The soil is residual in character. Unfortunately there is no feasible way of bringing water on this part of the island. It is at present used for sheep ranches and cattle range, being covered by a fine growth of nutritious grasses.

The finest body of agricultural land on the island is situated in the great gap, and has an area of about 14,000 acres. The principal problem of the water supply of the island is how to bring the water from that part which receives an abundant precipitation to this arid portion containing the rich soils. This area of gently rolling hills is covered by a deep-red soil unexcelled for purposes of sugar growing. To a great extent it is a sediment soil, as shown, for instance, along the western plantation fence near Mauna Loa Creek, where it follows the cane planted January, 1900. At this place a depth of from 20 to 30 feet of fine soil and disintegrated washed gravels is observed, resting on basaltic lava. This formation no doubt underlies a large portion of the cane lands. A part, however, of the eastern area on the rising hills is covered by residual soil derived from rock in place.

On the south shore there is a strip of low cane land near the coast at Palaau, but the main body of deep soil does not begin until an elevation of about 200 feet is reached. The total area of cane land at Palaau, below an elevation of 50 feet, is 374 acres.

Above an elevation of 800 feet, on the east side of the gap, there is, between the deeply incised canyons, a considerable amount of smooth land covered by grass and underlain by rich soil; but besides being cut up these areas are, by reason of their elevation, less suited for sugar cane, though well adapted for other crops. Thus, at an elevation of 1,400 feet, on the Meyer ranch, coffee is successfully cultivated in shady places without irrigation.

East of this point the island contains a relatively small amount of economically valuable soils. On the south coast the rocky slopes reach almost to the sea, leaving only in places narrow fringes of level land. On the north side the mountains, as indicated above, are very precipitous, and there is no arable land except small patches along the coast at the mouths of the rivers.

At high elevations the rock is, as a rule, much decomposed and retains water much better than do the stony slopes lower down. In the high swamps the mud is rarely over 2 feet deep, and solid, though decomposed rock comes frequently to the surface. The color of the soil in the swamps is grayish or white, showing that only ferrous oxide, produced by the reducing influences of organic acids, is present. After the swamps have dried up and the trees and ferns die, as has happened

over large areas in the high central parts of the island, this ferrous oxide under the influence of the air rapidly changes to ferric oxide. This forms a dark-red, hard-pan area on the surface which is very detrimental to young plants just rooting. This compact, dark-red soil is really an iron ore. A sample examined by Dr. E. T. Allen contained 43.88 per cent of metallic iron. This is one of the reasons why the reforesting of dried swampy areas is such a slow and difficult process.

For some distance east of Palaau there is a strip of sediment land along the coast containing 110 acres. Toward the sea this is joined by a salt marsh and toward the north by a rocky slope, which in part, however, can be planted. Near the cocoanut grove, 1¼ miles west of Kaunakakai, are 150 acres of excellent level soil underlain by 5 to 10 feet of coral which again rests on solid lava. At Kaunakakai about 100 acres of level rich soil are available. Between Kawela and Kaunakakai is a narrow strip of soil—mostly coral sand—which is covered by a thick growth of algarobas. At Kawela there is a considerable extent of sandy soil, practically all of which belongs to small native holdings. At Kamalo again several hundred acres of good soil are available, and from this place to the east point of the island a number of more or less extensive flats follow the coast, many of which are cultivated on a small scale. The lower part of the valleys of Halawa, Wailau, Pelekunu, and Waikolu contains a small amount of lands chiefly devoted to the growing of taro on a small scale.

VEGETATION.

In regard to vegetation, the southern side of the island may be separated in several zones. There is first the immediate coast fringe, distinguished by cocoa palms and algarobas; the barren zone; the belt of the grass lands; and finally the high forests.

The southern coast is fringed by a narrow, bright-green zone of thick and luxuriant algaroba trees (a variety of mesquit) which furnishes excellent firewood. The abundant bean pods of the tree are used as forage for cattle and horses. This strip is only a few hundred feet wide, but extends from Kawela Creek, almost without interruption, to a point a few miles west of Palaau. The western coast supports at Papohaku a few small and stunted groves of the same tree; the northern and eastern coast is too humid to permit the growth of this essentially arid-land tree. Occasionally, near springs at the seashore, the lahale trees appear, with clumps of bare trunks and palm-like tufts of leaves. This produces a fiber used for the manufacture of hats, etc. There is a large cocoanut grove one mile west of Kaunakakai. Few groves of this palm are planted east of this on the southern coast, though many places are excellently adapted for this purpose. Big thickets of the obnoxious weed Lantania grow on the coast near Kawela.

The barren zone of rough lava bowlders, with only a few bushes adapted to a dry climate, extends along the south coast, from the western point of the island to beyond Kamalo on the east. At Palaau it reaches an altitude of 200 feet; at Kaunakakai, 1,000 feet; and at Kawela, 2,000 feet. Toward Mapulehu the grasses reach sea level.

The pasture lands are covered by a thick carpet of manania (a variety of Bermuda grass) or delicate tufted Pele grass. Above a certain elevation (about 500 feet on the west end) these give way to annual grasses. Almost the whole of Kaluakoi, or the west end, is covered by pasture land; likewise the gap, excepting the arid strip near Palaau. Both of these areas are practically treeless. During the arid season the grass dries up. In the creeks and canyons east of the gap are found groups of kukui trees, with their smooth trunks and yellowish-green foliage bright with an almost silvery sheen. This is also called the candle tree, on account of producing a nut rich in oil. Many of these groups show signs of damage by cattle.

Isolated wili-wili trees are also noted, with their coral red bean and peculiar habit of shedding their leaves in the summer. Scattered cactus trees and hau bushes complete the meager flora of this zone. The finest and healthiest groves of kukui trees are found in the different branches of Meyers Creek above Meyer's ranch at elevations of about 1,000 feet. Parasitical ferns grow in profusion on the tree trunks. Papaia trees and coffee bushes do well wherever planted in these shaded canyons.

As the elevations increase, the grassy ground gradually becomes more swampy. Near Meyer's ranch the pastures are diversified by thick bushes of wild guavas, and ferns grow luxuriantly in the little gulches. Going upward from Meyer's ranch over swampy pastures and partly decayed forests, sometimes crossing little canyons thick with a growth of ferns, one is suddenly and unexpectedly stopped by the great precipice, the northern pali, here descending abruptly 1,500 feet to the sea, and showing along its steep escarpment the broken succession of the dark lava flows (Pl. IV, *A*). Far below, a silvery white fringe of breakers marks the shore. A rocky peninsula extends at the foot of the pali, and on its western side we notice a prosperous-looking town with regular streets and white cottages. Several churches and larger buildings are also seen, and many of the houses are surrounded by bright green gardens. This is the leper settlement of Molokai. A steep and somewhat dangerous trail leads down to the town. The inmates of the settlement are not allowed south of the pali, and at the little gate at the summit of the trail the unfortunates confined in the settlement often meet their friends.

In this vicinity the forests begin at an elevation of 2,500 feet, but the trees are in poor condition and on large areas are dying. It should be observed that all forests on this island grow on swampy ground. Open forests with trees growing on dry ground do not exist. The

lehua, a myrtaceous tree, in several varieties is most abundant. It has dark-green foliage and bright-red flowery tassels during the spring months. The height is usually up to 30 to 40 feet. More common on the north slope is the ohia or mountain apple, and the koa with its exceptionally hard wood. Around the moss-covered roots, frequently branching above ground, cluster the thick ului ferns (*Glauchenia*), and intermingled with the lehuas rise the pulu ferns (*Cibotium*) with their widespreading fronds up to 15 feet high. The whole is interwoven with a mass of tough eea vines (a kind of *Pandanus* or climbing screw pine) to a thicket which usually is almost impenetrable except along the beaten trails.

From Meyers Lake to east of Kaulahuki the forests, once said to be thick and healthy, are in a decaying condition. Kalamaula swamp is now partly dried. Around Kaulahuki extends a comparatively dry high plateau, and the peak itself is easily accessible. Going up over this plateau, rolling, grassy, and cut by sharply eroded little canyons, one comes suddenly to the great alcove canyon of Waikolu. The plateau is cut off sharply as with a knife; the eye sweeps down the black abyss of the precipices of the Upper Waikolu, and then down the V-shaped canyon to the sea. Narrow streams of water descend the faces like silvery threads on a black background. But at every place where there is a possibility of foothold a rank vegetation covers the rocks, and where the walls become a little less abrupt there is a solid area of dark-green foliage. At the brink of the canyon the mornings are often calm and clear, but before noon the sky and the sea mingle in one hazy bank and the strong trades drive dripping mists and intermittent showers over the swampy highlands.

A short distance east of Kaulahuki the horse trail ends and the whole country is covered by thick, healthy vegetation. Above Kawela the forests formerly descended far below Kolekole hill to an elevation of 3,000 feet. In its normal healthy condition the forest now extends along a width of only one-half mile on the southern slope. Traversing this thick swamp, clambering over slimy, moss-covered roots, and wading through deep mud, one suddenly emerges on the Pelekunu pali at an elevation of 4,500 feet. From this point can be seen the whole of Pelekunu drainage and part of Wailau, a green, impenetrable wilderness bordered by nearly perpendicular cliffs. Trails are said to cross the island into Waikolu and Pelekunu, but they are dangerous and difficult.

From Mapulehu an exceedingly bad though not particularly dangerous trail leads over into Wailau. Guided by Mr. Theodore Meyer I ascended the steep grassy slopes from Mapulehu to a more gently sloping path between narrow canyons, along which kukui, wild orange, and guava grow in profusion. We made camp at the edge of the forest 1,550 feet above Mapulehu. The next morning at sunrise a magnificent view was obtained of Haleakala, Maui's great

volcano, with its gigantic crater, seemingly only a few miles distant, but within a short time the usual clouds again hid the summit of the mountain. The track now enters the forest and ascends 1,200 feet in 1 mile, through lehua roots and mud, to Wailau Gap, which has the comparatively low elevation of 2,750 feet. The forest seems healthy, but Mr. Meyer states that it is much more open than formerly, probably due to grazing of cattle. In this part of the island there are, however, few cattle compared to the number kept in the western part. From the summit the extensive view over Wailau Valley reveals the same impenetrable sea of dark-green forest relieved by bright patches of wild bananas and kukui groves. Over slippery moss-covered rocks the trail descends 2,000 feet in 1 mile to the east fork, which may be followed for half a mile, by wading through water or jumping from rock to rock, down to the junction of the two forks, at an elevation of about 600 feet. Some distance before the east fork is reached we passed an abandoned kuliana, or native settlement, with a taro patch and a few exceedingly welcome orange trees.

The Wailau is a comparatively large stream, and its waters rush with torrential force in the narrow canyon. There is no further cultivated ground until near the mouth of the river, where considerable taro is grown and sent over by steamer to the leper settlement, partly whole, partly crushed to so-called "paiai" and packed in ti leaves. Pl. III, *B*, represents the native crew of the little steamer *Mokolii* engaged in loading paiai. We returned the same day to the camp above Mapulehu. The excursion makes an extremely arduous day's work.

CAUSES OF DECREASE OF FOREST AREA.

Many theories have been advanced as explanations of the decay of the forest. It has been attributed to cattle, deer, and goats, to decrease of rainfall, and to a disease of the trees.

It is evidently true that for many years the island has been overstocked, especially the good pastures at higher elevations, and it can easily be understood how the damage to the trees is effected. The cattle do not kill the trees directly, but they destroy the thick growth of ferns and grass which protects the roots and which is evidently essential to the life of the lehua tree. They also eat the young trees just coming up from seed. This has assuredly been the most prominent cause. But in many canyons where cattle scarcely can find their way, as well as in some parts of the swamps near the Pelekunu pali, the lehua trees are also dying, which indicates that the tree is besides suffering from some insect or fungus. The deer do less harm than the cattle, but it may nevertheless be well to keep their number within reasonable limits. In lower elevations goats abound, which should be removed as thoroughly as possible, for they completely destroy the already scant vegetation. Sheep have lately been confined to the western end (Kaluakoi), which seems most suited to them.

All in all, I believe that the cattle, in part aided by the disease referred to, are responsible for the decay of the forests and that it is not necessary to assume any material changes in climate. As mentioned, there is no such decay noticeable at Mapulehu, where very few cattle have been pastured. In consequence of the drying up of the swamps, the rainfall runs off rapidly and the streams become more intermittent and torrential in character, as indeed is very clearly marked in the case of Kawela. To remedy these conditions, I can only suggest the exclusion of cattle and other fern-destroying animals from the upper mountain region, which may cause the swamp ferns and lehuas to grow up again. The hard pan mentioned on page 20 is a serious obstacle to reforestation. Planting certain areas of land below the swamps by eucalyptus, acacia, or Monterey cypress would remedy matters to some extent.

FAUNA.

As well known, the native Hawaiian land fauna is exceedingly scant. A number of small birds inhabit the forests. Excepting a few centipedes, the objectionable insects are few in number. Many varieties of tree snails are found, often of beautiful color and delicate shell sculpture. More species of these are said to occur on Molokai than on adjacent islands.

The introduced animals are deer, goats, and cattle. The deer are of the spotted Japanese variety and have multiplied rapidly, so rapidly, indeed, that it has been found necessary to attempt to reduce their numbers, as they do considerable damage to the vegetation. Their principal range is on the high plateaus a few miles east of Meyer's ranch at the edge of the forest. The goats have likewise proved a nuisance, and it is difficult to keep in check their rapidly growing numbers. They chiefly range, practically wild, over the arid portion of the southern slope. It is surprising to observe their gymnastic performances when a band of them is scattered browsing on the ledges of canyon cliffs which a casual observer would pronounce perpendicular. The sheep kept on the Molokai ranch are chiefly confined to the western end of the island. Most of the cattle are now kept on Molokai ranch, including the west end, the gap, and a part of the southern slope as far as Kawela. Some of them run almost wild, but attempts are made to reduce that number, and also to keep them off the high forest areas. The island has been heavily overstocked with cattle, but the number is now reduced. East of Kawela there are comparatively few. For a limited number the western half of the island is a most excellent range.

CULTURE.

Tradition has it that in former days Molokai supported a far greater number of inhabitants than at present, and, further, that the forest covered much greater areas, even occupying part of the now treeless west end of the island. While, as explained above, it is doubtful

whether the rainfall has decreased, it is certain that with the destruction of much of the forest areas an equalizing element of much importance has been eliminated. From one end of the island to the other the coast abounds in stone fences and heiaus or square inclosures of stone connected with the worship of the gods. Evidences of old cultivation are apparent at a number of now arid places. Abandoned farms are found in the valley of Wailau; on the Pelekunu, a mile or two from the coast, old abandoned plantations of pineapples were noted. Such cultivation as now may be carried on by the natives is shiftless and imperfect. Taro is raised in the Lower Wailau and Pelekunu. Rice fields are cultivated by Chinese at intervals along the southern coast. A few small cocoanut groves are planted, but there is only one large grove, near Kaunakakai, said to have been planted by Kamehameha V. Small scattered kulianas contain a few oranges, mangoes, and papaias. On the whole, it is clear that with proper care and industry the island could support a far greater number of people than dwell on it at present. To some extent this undesirable state of affairs is doubtless due to the consolidation of properties into larger holdings for prospective sugar cultivation. But there is also a decided tendency of the natives to sell their small holdings and to move away to centers like Honolulu. The ranch of the Meyer Brothers, located about 5 miles north of Kaunakakai, shows what can be done even with comparatively small holdings when intelligent care is applied. Cattle are raised here, as well as some coffee and other products.

The population of the island aggregates about 2,400; but over 1,000 of this number are located in the leper settlement on the northern coast, established in 1865 and embracing about 8,000 acres. Of the remainder, several hundred are probably Japanese laborers, as the census was taken in 1900, when there were many of this class at Kaunakakai and Kamalo, so that there would remain only about 1,000 people scattered at Pelekunu, Wailau, Halawa, and the southern coast as far west as Kawela, for along the real arid part of the coast there are but few inhabitants. The total assessed value of Molokai was only $250,000 in 1897. In 1900 this figure had increased to about $686,000, due to the projects for sugar plantation advanced that year. In 1901, after the partial failure of these attempts, the assessed value decreased to $427,000. The Molokai Ranch Company, a corporation, controls the larger part of the lands on the western part of the island as far east as Kawela, and make a successful business of raising cattle and sheep on the extensive grass lands.

The American Sugar Company, closely connected with the Molokai Ranch Company, began operations in 1898 and 1899, controlling nearly the whole of the rich body of land in the gap, and the coast as far east as Kawela. It was proposed to bore for water at Kaunakakai, where 10,000,000 gallons per twenty-four hours (15.47 cubic feet

per second) were expected, and to raise this by means of pumps to an elevation of 400 feet to a ditch conveying it to the cane lands below the 350-foot level. It was further intended to obtain 20,000,000 gallons (30.94 cubic feet per second) 1 mile east of Kaunakakai and conduct it to a point 2½ miles away, where the water was to be lifted 500 feet to a short ditch conveying it to the lowest point of the gap, whence it could be distributed on both slopes. Eighty acres of seed cane were planted on the Kaunakakai flats and irrigated from a well giving 1,000,000 gallons in twenty-four hours (1.55 cubic feet per second). The failure of the Kaunakakai wells to produce the amount expected caused a change in the plans. It was decided to bore wells at the mouth of Kawela Gulch and raise the water about 70 feet to a cement-lined aqueduct, which should convey it to the high-lift pump mentioned above. Here, too, however, the quantity obtainable at one point seemed insufficient, and difficulty was experienced in avoiding contamination by salt water. Attempts were also made to find water by deep borings. In 1900 the company decided to abandon operations for the time being, and thus the problem how to obtain water for the rich sugar lands at the gap still remains unsolved.

The Kamalo Sugar Company controls the coast from Kamalo to Mapulehu. In this distance there are a number of smaller flats aggregating a considerable area. It was proposed to utilize these for sugar cane by wells bored along the coast and raised to a ditch about 70 feet above sea level. A small area of sugar cane for seed was planted at Kamalo and irrigated by means of a permanent small stream at the head of Kamalo Gulch. The water was taken out a short distance east of Kolekole Peak and temporarily conducted down in a ditch along the ridge. As Kamalo Gulch often contains running water, it was also proposed to utilize this source.

WATER SUPPLY.

GENERAL PRINCIPLES.

The fundamental law governing the water supply is that the only source of fresh water is the rainfall. A part of this rainfall is carried off by evaporation, another part by the streams, while a third and largest part sinks into the ground and gradually finds its way to the ground water, which permanently saturates the rocks below a certain level.

But on this small island, built up of extremely porous rocks, and surrounded by salt water, peculiar conditions result. In the absence of any impermeable stratum or basins filled by clayey material, such as, for instance, exist on Oahu, there is nothing to prevent the sea water from penetrating the rocks freely and assuming a level differing but little from the sea level. Below a certain level there is indeed no reason to expect anything but salt water.

On the other hand, the rain water also sinks freely through the porous rocks until it meets the sea water. Here, at the permanent water level, it is held by the counter pressure of the sea water, and in fact rests like a sheet on the same. Between the underlying salt water and the fresh water on top of it there is an intermediate zone of varying width in which the two mingle to form brackish water. The fresh water, always receiving additions from above, is slowly but steadily moving to the only outlet it can find—that is, to the springs located along the sea shore, just above or a little below sea level.

The surface of salt water is, apparently, near the coast on the south side of the island, about 160 feet below the surface of the ground. Inland this level sinks, and is also doubtless deeper on the north than on the south coast. The permanent surface of fresh water rises inland very slowly, so that a mile or more inland the water in wells may stand only a foot or two above sea level. Only at Kawela, a few hundred feet from the coast line, is the water level from 2 to 3 feet above mean sea level, and in this place a more abundant underground water supply is found than at any other point west of it. This generally low level of ground water is a distinctly unfavorable sign, pointing to small precipitation and water supply.

The one feature favorable to the percolation of the water to the southern coast line is that the lava beds all slope in this direction—that is, toward Palaau, Kaunakakai, and Kawela—thus to some extent guiding the water in this direction.

On the north coast the permanent water level is much higher, as indicated by the number of strong springs coming out at elevations of from 300 to 500 feet above sea level.

Above the surface of the ground water there may be some movement of water in cracks and fissures, but there is no permanent and abundant supply, certainly not on the south slope. Thus, tunneling on this slope is not apt to develop any considerable amount of water, though it may open some small fissures in which water circulates. As a matter of fact, very little water has been developed by the several tunnels driven near springs at higher elevations. If it were possible to drive a tunnel with very slight grade from sea level or from near the same, such an opening might develop a considerable amount of ground water; but this would be attended with many difficulties.

There is considerable irregularity in the amount of water available below the ground-water level. The porosity of the rock changes very rapidly; open, loose agglomerates are laterally adjoined by hard, much more impervious basalts. Further, the drainage conditions vary, the ground-water surface rising higher in one place than in another; thus in closely adjoining wells there may be great difference in the amount of water available from the same level.

The water from the flowing streams and from the springs emerging at high elevations contains practically no chloride of sodium, this being the only saline constitutent necessary to consider.

In the ground water along the coast the salinity is decidedly higher except where the ground water is mingled with water sinking from intermittent streams. The salinity increases with the distance from the center of maximum precipitation. Thus, at Palaau the water contains 90 grains, at Kaunakakai 50 grains, and at Kawela 25 grains per gallon.

In the following pages the available water resources will be described under the head of springs, streams, and wells.

SPRINGS.

The springs coming out on the southern slope of the island may be divided in three classes: First, those emerging at sea level. These are very numerous, and often, by reason of their vicinity to seashore, more salty than the normal ground water. Second, those appearing at elevations from 1,000 to 2,500 feet. Between the sea level and 1,000 feet no permanent springs appear, at least not west of Kamalo. Third, those of the summit region feeding the permanent streams. These will be mentioned under the heading of "Running streams."

On the north coast springs are more numerous and larger and emerge at any elevation. Strong springs appear in the Wailau and Pelekunu at from 300 to 600 feet above sea level.

SPRINGS ON SEASHORE.

No permanent springs are known on the whole north and west coast of Kaluakoi or the west end. A small spring has long been known to emerge on the south side of the ridge, near the summit, 2 miles east of the light-house, at at elevation of 180 feet, but it dried up in 1898 and has not been running since. At Waiakane, well below high tide, a strong spring of fair water appears.

The next important locality is Palaau. In the grassy marsh below the deep well big springs come out for a distance of 700 feet. Many old taro patches indicate that this water has been used. One of these springs flowed about 60,000 gallons a day (0.09 cubic foot per second), and the aggregate flow must be large. A sample yielded 103 grains of sodium chloride per gallon. On Naiwa, between Palaau and Halfway Camp, near a lone cocoanut tree, strong springs emerge from clefts in the basalt rock at the beach, 1 foot above high tide; the total visible flow may be as much as 170,000 gallons in twenty-four hours (0.26 cubic feet per second), and the salinity is 127 grains.

Half way between Palaau and Kaunakakai again a number of smaller springs appear, with a salinity of 86 grains per gallon. They emerge 1 or 2 feet above high-tide level.

The next locality is Cocoanut grove, 1 mile west of Kaunakakai, when very strong springs come out from the sand at the shore for a distance of 150 feet. The total flow is difficult to estimate, but it may

be over 200,000 gallons in 24 hours (0.31 cubic foot per second). The water contains 115 grains of sodium chloride per gallon.

Near Kaunakakai there appear to be no springs of importance, but 1 mile eastward, close to the road, a strong spring comes out from the basaltic rock at the foot of a bluff, 1 foot above sea level. Flow, approximately 6,000 gallons in 24 hours (0.01 cubic foot per second). The water contains 76 grains sodium chloride per gallon.

From this place to a point 1,000 feet east of Onini triangulation station no springs were seen at sea level, though wells find water at a depth of a few feet in most places, the sodium chloride in these amounting to about 115 grains. At the locality just mentioned a strong spring appears, and for a distance of several hundred feet much water comes out along the beach. The total flow must exceed 200,000 gallons in 24 hours (0.31 cubic foot per second). The sodium chloride amounts to 72 grains per gallon. A little water comes out east of this point as far as the end of wall around the fish pond. Again, small springs appear at the kulianas, just west of the mouth of Kawela Gulch. All of these springs east of Onini are under water at high tide.

The largest springs noted appear in the rice field east of Kawela Gulch, at the foot of a little bluff; they are 1.5 feet above sea level, and the aggregate volume of water measured by the discharge from the rice field is 450,000 gallons in 24 hours (0.70 cubic foot per second). The water contains 12 grains of sodium chloride per gallon. East of Kawela the coast was not examined in detail. Probably the coast springs continue all the way to Halawa and are fully as strong as at Kawela.

HIGH-LEVEL SPRINGS.

On the south slope, west of Kamalo, the springs issuing between 1,000 and 2,400 feet above sea level are exceedingly few in number.

The gulch heading north of Meyers at Puu Lua and emptying into the sea after flowing a few miles westward contains three springs. The principal one, at an elevation of 1,300 feet, yields at least 30,000 gallons in twenty-four hours (0.05 cubic feet per second), has no salt, and on May 21 flowed on the surface for a distance of at least one-half mile. Water comes out for a distance of about 1,000 feet; at the head two short tunnels have been run into the side hill without increasing the flow. At this place there is a watering trough, but the spring is said to be apt to run dry toward the end of the dry season. Another small spring inclosed by a stone wall is found in the next gulch just below Puu Lua. Lower down in a tributary to the same gulch, at an elevation of 1,000 feet, a little permanent water trickles out from the side and supplies a watering trough.

In the same vicinity, on Meyer's ranch, are two permanent springs. The first, 1,500 feet east of the trail to the leper settlement, at an elevation of 1,500 feet, yields continuously about 20,000 gallons in

twenty-four hours (0.03 cubic feet per second). The second, developed by a tunnel 300 feet long, drains toward Meyers Gulch and furnishes about 40,000 gallons (0.06 cubic feet per second), nearly all of which was developed by this tunnel.

A well-defined spring is that of Kapuna, at an elevation of 1,630 feet. This probably yields about 40,000 gallons (0.06 cubic feet per second), which is conveyed in a pipe line to the Molokai ranch. The water contains 3 grains of sodium chloride per gallon. It is permanent in all seasons according to reports. A short tunnel has been run in under the bottom of the gulch, but it failed to develop any additional amount of water.

In that branch of Luahine Gulch heading at Hunter's cabin, at the old wagon road leading up to the summit, a spring appears on the west side at an elevation of 2,400 feet, 30 feet above the bottom of the gulch. Its permanency is indicated by a bunch of wild bananas growing close by. The flow was measured on May 28, and was found to be about 77,000 gallons a day (0.12 cubic feet per second). The water is practically free from salt, but, according to reports, it dwindles down to a fraction of this amount during the driest part of the season. A tunnel 800 feet long has been run in under the hill in a north-northeast direction below the Kalamaula Swamp, but very little additional water was developed. The water comes out from the side and roof for short distance, while the rest of the tunnel is simply moist, giving no flowing water.

The only remaining spring at middle elevations is on Kawela, near its east boundary, in the gulch near Foster's mountain house, at an elevation of 2,500 feet. The water, which is pure and cold, amounted to 10,000 gallons a day (0.02 cubic feet per second), when visited, but the amount is less in very dry weather. From this point to Halawa no detailed examination has been made, but it is probable that springs are somewhat more frequent. At Mapulehu the swampy forests descend to 1,400 feet above the sea, and many springs are found at their lower edge.

RUNNING STREAMS.

STREAMS OF THE NORTH COAST.

On Kaluakoi there are no permanent streams; the gulches contain water only for a short time after heavy rains. Mauna Loa Gulch, emptying near Palaau, is the only one in whose upper course a little water runs during the larger part of the rainy season.

The gulches on the north coast west of the leper settlement are also dry except during heavy rains. The running streams to be considered are as follows: On the north coast, Waihanau, Waialeia, Waikolu, Pelekunu, and Wailau; at the east point, Halawa; on the south slope: Meyers, Kaunakakai, Kawela, Kamalo, Mapulehu, and Waialua gulches.

Waihanau.—The lower part of the Waihanau is a deep recess cut back from the pali, and over the edge of this recess, as indicated on the map, the stream flows in a series of falls. In the lower part of the valley the stream does not run during the summer. The upper part, which alone is considered here, has a drainage area of only about one square mile, but receives a great deal of rain water. Swamps line its borders, and much water comes in from springs on the sides of the abrupt canyon in which it flows, and which has a depth of from 300 to 500 feet. The grade is about 100 feet in 2,000. In the upper portion the stream is permanent though low in the dryest part of the season. I am informed by Mr. D. Center, the manager of the plantation at Kaunakakai, that when at its lowest stage the water will fill a 4-inch pipe lying nearly horizontal. This would correspond to about 80,000 gallons in twenty-four hours, (0.12 cubic feet per second). When visited on April 25, the flow was about 2,500,000 gallons a day (3.87 cubic feet per second), at an elevation of 2,046 feet. The weather was showery. On June 22, after three weeks of uninterrupted clear and warm weather, it flowed 1,500,000 gallons (2.32 cubic feet per second). On June 25, during the beginning of showery weather which continued for three days, the flow was 8,500,000 gallons (13.15 cubic feet per second). These results were obtained, as all of the following, at places where the stream ran with slight grade above and fell over an easily measurable natural weir, and should be accurate within 10 per cent. I conclude that the stream can be relied on for 3,250,000 gallons per twenty-four hours (5.03 cubic feet per second) from November 1 to June 1, for 1,000,000 gallons (1.55 cubic feet per second) from June 1 to August 1, and for at least 100,000 gallons (0.15 cubic foot per second) from August 1 to November 1.

Waialeia.—This stream has formed a deep recess from the pali, shorter but wider than that of the Waihanau. Over the nearly perpendicular wall of this recess it falls in cascades. The water in the lower part of the valley sinks during the dry season. Only the upper part above the precipice is here considered; it forms a small canyon extending back for a mile to Puu Kaeo. The watershed is only one-half of a square mile, but the supply is permanent, being fed by springs.

During the driest part of the season it fills, according to Mr. Center, a 2-inch pipe laid nearly horizontally. This would correspond to about 16,800 gallons in twenty-four hours. Measured May 24, during showery weather, at an elevation of 2,820 feet, a flow of 400,000 gallons (0.62 cubic feet per second) was obtained, which may be taken to correspond to average flow from November 1 to June 1.

Waikolu.—The Waikolu is a still larger and deeply cut canyon, surrounded near its head by almost perpendicular precipices, 2,000 feet in height. From the summit region belonging to its drainage three streams fall in grand cascades over these precipices. The

stream carries permanent water, which is used in the bottom of the valley for growing taro, the water rights of the lower part belonging to the leper settlement.

The area drained by the western branch of the Upper Waikolu is only one-half of a square mile, but practically all of it is swampy lands, insuring a good supply, permanent, though small, even through the dry months. The stream has cut a small canyon about 300 feet deep in this swampy plateau. The water was measured at an elevation of 3,645 feet on May 31, after three days of warm, clear weather following showery weather, which are practically normal conditions. The flow was 1,250,000 gallons (1.93 cubic feet per second), which may be accepted as the normal for the rainy season. The two other branches of the Waikolu head on the swampy, almost inaccessible plateau between Waikolu and Pelekunu.

Pelekunu.—Like the others on the north coast, this stream has cut a deep, alcove-like recess from the pali along the coast, continuously surrounded by precipices from 2,000 to 3,000 feet high. The highest part of this precipice is toward Kawela, while a narrow backbone, with an elevation of 2,500 feet, separates it from the headwaters of the Wailau. The watershed has an area of 7 square miles. In its lower course the grade of the stream is about 100 feet per 2,000, but above elevations of 1,000 feet it becomes very steep. The whole area is covered by extremely dense vegetation of ferns, lehuas, kukui, eea vines, and in many places wild bananas and mountain apples. Many large springs swell the lower course of the Pelekunu, coming out at elevations of from 300 to 600 feet. At an elevation of 350 feet the stream forks, the west branch again forking above this at an elevation of 425 feet.

On June 15 I visited the lower course of the river, ascending from the coast, there being no safe trail from the south side of the island to Pelekunu. The landing at Pelekunu is difficult, and on account of the heavy surf, practically impossible during the winter months. The weather for two weeks had been clear and warm, following a period of showers. The east branch of Pelekunu, measured at an elevation of 400 feet, contained 5,300,000 gallons (8.20 cubic feet per second). The middle or main branch, measured at an elevation of 475 feet, contained 11,700,000 gallons (18.10 cubic feet per second), while the west fork at the same elevation contained 4,500,000 (6.96 cubic feet per second), making a total of 21,800,000 gallons in twenty-four hours (33.73 cubic feet per second), from a watershed of 4 square miles. The question of minimum flow is a difficult one to answer without any measurements during the driest part of the season. A total of 5,000,000 gallons (7.74 cubic feet per second) at an elevation of 500 feet is certainly conservative; more probably the least flow would be 6,000,000 or 7,000,000 gallons (9.28 or 10.83 cubic feet per second). More observations during September or October are necessary to settle this point.

Wailau.—This, the largest stream of the island, is in general characteristics very similar to the Pelekunu. Its drainage area is slightly larger and is covered by the same dense vegetation. Precipices like those at Pelekunu, though scarcely as steep, surround the basin, which is narrower toward the sea than toward the head. A difficult foot trail connects Wailau with Pukoo and Mapulehu and crosses the mountain at a pass with the low elevation of 2,800 feet. From the summit gap the trail descends along the ridge between the two principal forks and reaches the east branch at an elevation of 690 feet; then it follows this for some distance and ascending again over the small point Puu o Wailau (elevation 680 feet), it reaches the junction of the forks at 470 feet. At the time of the visit, June 5, clear weather had prevailed for one week over the whole island, following showery weather in the end of May.

At an elevation of 500 feet the east fork contained 7,500,000 gallons (11.60 cubic feet per second), and at the same elevation the west fork contained 14,100,000 gallons (21.82 cubic feet per second), thus giving a total of 21,600,000 gallons in twenty-four hours (33.42 cubic feet per second) from an effective drainage area of 5 square miles. It will be noticed that the Wailau and the Pelekunu differ but little in their total flow; while the drainage area of the latter above 500 feet is slightly smaller, the elevation of its watershed and the precipitation is probably somewhat larger than that of Wailau.

Regarding the minimum flow the same remarks apply as have been made regarding the Pelekunu. Ten million gallons (15.47 cubic feet per second) is a liberal estimate of the least flow; more likely it is 8,000,000 gallons in twenty-four hours (12.38 cubic feet per second).

Several minor streams descend like silvery threads from the pali into the sea between Wailau and the eastern end of the island. Sometimes the strong trade winds dissipate these cascades into mist before they reach the foot of the escarpment.

Halawa.—Very near the eastern promontory the important watercourse of Halawa empties into the sea. Halawa differs from the other streams in flowing in an almost due east direction. Its watershed comprises about 8 square miles; it has its source in the swampy, impenetrable plateaus east of Wailau, and it descends from these in a beautiful waterfall plainly seen from the harbor. For a mile or two above its month it flows in a somewhat open, fertile valley. The minimum flow of Halawa is reported by Mr. O'Shaughnessy, former engineer to the American Sugar Company, to be about 5,000,000 gallons in twenty-four hours (7.74 cubic feet per second).

STREAMS OF THE SOUTH COAST.

Meyers Gulch.—This stream has a drainage area of 16 square miles, the largest on the south coast, but except near the summit it contains no permanent water, not even during the winter months. Its canyon

is sharply cut into the grassy plateau to a depth of from 200 to 300 feet, and contains in places thick groves of kukui trees. It empties a short distance east of Palaau. The grade in the lower course is moderate, but above an elevation of 1,500 feet it increases rapidly and the canyon contains many abrupt falls. The uppermost courses of the different branches have again a more gentle grade. At an elevation of 700 feet the creek branches. The east, or Luahine, fork heads with two prongs near the Hunter's cabin, on Kaunakakai land division, at an elevation of 3,000 feet; the main branch continues by Meyer's ranch, where it is joined by several smaller branches extending up toward Meyers Lake, and 1 mile above Meyers divides again into the Kahapakai and the Mokomoka branches, both of which head at elevations of about 2,600 feet in Kalamaula swamp.

During the winter of 1899–1900 the water in this gulch reached the coast four times—in December, April, May, and, lastly, June 27 and 28. The volume is considerable, sometimes 5,000,000 to 8,000,000 gallons in twenty-four hours (7.74 to 12.38 cubic feet per second), but the flow subsides rapidly. On June 27 about 5,000,000 gallons came down in twenty-four hours (7.74 cubic feet per second), while the next day there was but a slight stream trickling along the bed.

The permanent water appears chiefly in the Kahapakai Fork. Near its head, which is separated only by a narrow ridge from the canyon of the Waihanau, it is fed by strong and continuous springs coming in chiefly from the east side. Between 2,000 and 1,500 feet there is a sharp grade. Though the flow is small in summer the water runs permanently as far down as Wahii (elevation, 1,475 feet), where one branch of the water pipe supplying the ranch ends. Below this, on May 26, a little water was running, but only as far as the junction of the two forks.

On May 24, in light showery weather, Kahapakai was measured at an elevation of 1,975 feet, and flowed 281,000 gallons (0.43 cubic foot per second), diminishing at an elevation of 2,200 feet to 192,000 gallons (0.30 cubic foot per second). The same creek, at an elevation of 1,975 feet, contained on June 25 (light showers following three weeks of drought) 155,000 gallons (0.24 cubic foot per second). On May 26, after some pretty heavy showers, the water at Wahii measured only 151,200 gallons (0.23 cubic foot per second), showing that the maximum flow is at a considerably higher elevation.

The Mokamoka Fork does not contain as much water, nor is it permanent during the summer. On May 26 it was running only a little water one-fourth of a mile above the mouth of Kapuna Spring Gulch. Its average flow during the rainy season, at an elevation of 2,000 feet, may be estimated to be 150,000 gallons (0.23 cubic foot per second). The Luahine Fork of Meyers Gulch branches at an elevation of 2,000 feet, the two forks heading on each side of Kalualohe Hill. The west fork carries some water, about 100,000 gallons (0.15 cubic foot per

second), in the rainy season, and is said to run some throughout the summer. The east fork contains the spring mentioned above. The flow begins one-half mile above the tunnel and continues for at least the same distance below it. The maximum flow is perhaps 1,000 feet below the tunnel. On May 30 it gave 135,000 gallons (0.21 cubic foot per second).

Kaunakakai Gulch.—This gulch, debouching at Kaunakakai, has cut a long, narrow box canyon, and embraces a watershed of about 8 square miles. It has a very straight course and is from 100 to 400 feet deep, the maximum depth being attained at the junction of the forks below Kaulahuki. From the west it receives some deeply eroded tributaries heading at Hunter's cabin, but these are usually dry, even through the rainy season. The main canyon has near the mouth a grade of about 100 feet in 1,500. In its middle course it is very steep, while on both sides of Kaulahuki lighter grades again prevail. The gulch contains running water in its middle and lower course only after heavy rain storms. Occasionally, very heavy freshets flood the plain at its mouth and bring heavy bowlders from the canyon. It is, in brief, a typical torrential stream. During the winter of 1899–1900 it was in flood in December; again in April, and finally in the last days of June, but each time the volume diminished rapidly, and after twenty-four or twenty-eight hours had dwindled to a very small amount. Below Kaulahuki, at an elevation of 2,500 feet, the main canyon forks—one branch, the Kamiloloa, heading between Kaulahuki and Kaeo, while the other, the Makakupaia, heads in the swamps around Hanalilolilo. Both of these branches carry permanent water. Kamiloloa during the period of examination carried water from its extreme head down to a point 3,500 feet above the junction. It is largely spring fed and its permanency is attested by a big bunch of wild bananas growing in the canyon at an elevation of 3,100 feet. On April 29 there was at least 200,000 (0.31 cubic foot per second) or 300,000 (0.46 cubic foot per second) gallons running. On May 31, after three warm, brighter days following showery weather, a flow of 276,000 gallons (0.43 cubic foot per second) was measured at an elevation of 3,100 feet. According to apparently reliable accounts it dwindles in extremely dry weather to 20,000 gallons (0.03 cubic foot per second). The main bulk of the water comes from the Makakupaia Fork, which is fed partly by springs but largely by the water stored in the swamps about Hanalilolilo. Below this point the Makakupaia forks again, both branches carrying water, though the eastern branch contains the larger part of it. The water, as in all of the streams heading in swampy ground, is of brownish color. The flow is continuous, even in the driest season, but, as in the case of Kamiloloa, it dwindles to a small amount. In the rainy season the water runs for a distance of several thousand feet below the junction, and even in the dry season it usually reaches the junction, according to state-

ments of Mr. Theodore Meyer. The stream was measured May 31, under normal conditions, three days of fair weather following showery weather, at an elevation of 2,510 feet. A flow of 450,000 gallons (0.70 cubic foot per second) was obtained.

Onini Gulch.—Though heading at 3,000 feet this gulch is ordinarily dry up to its head, only flowing after heavy rains.

Kawela Gulch.—The Kawela drains a territory of about 3½ square miles It heads in the swamps near the highest peaks of the island and flows in a narrow box canyon from 100 to 500 feet deep. The grade near the mouth is 100 feet per 2,000, but in the middle course it increases to extremely sharp descents, broken by many perpendicular falls. In its upper course the grade is again less, perhaps averaging 100 feet in 1,000 feet.

Like Kaunakakai, this is a pronounced torrential stream, but it carries considerably more water. During the rainy season its flow very frequently reaches the sea continuously for several days. On an average the Kawela is in flood at least once a month between October and June. There is a great deal of water under its sandy flood plain, and the flow during freshets is depended upon to irrigate the kulianas (small holdings of native settlers) near its mouth. The flood does not stop suddenly, as in Meyers and Kaunakakai gulches, but continues for several days. The volume of water coming down is very large. On May 1, several days after showery weather, the Kawela, 500 feet above the forks, at an elevation of 160 feet, flowed at least 300,000 gallons (0.46 cubic foot per second), which at an elevation of 100 feet diminished to about 100,000 gallons (0.15 cubic feet per second). On May 28 Kawela had been flowing strong for several days; at an elevation of 100 feet there was a flow of 3,000,000 gallons (4.64 cubic feet per second). This gradually diminished, and on June 11 the creek was dry at the junction of the forks. On June 26 the creek was in flood again and continued so for several days, the amount on the day mentioned being at least 6,000,000 gallons (9.28 cubic feet per second).

The Kawela branches three-fourths of a mile above its mouth, and the two canyons have a parallel course only 1,000 to 2,000 feet apart to near their heads. Two miles above the mouth the west fork receives two tributaries which, however, are dry even during rainy season. The main west fork heads near Hanalilolilo and carries a little water, which rarely reaches the main junction. The ordinary winter flow is continuous for 2 miles below the head to a point below the high-water fall at an elevation of 3,000 feet, which may be observed from near Onini station. The flow was measured under normal, average winter conditions at an elevation of 3,350 feet, where its grade is comparatively flat, the result being 190,000 gallons in twenty-four hours (0.29 cubic foot per second). This little stream is probably nearly dry in the fall.

The main or east fork under average winter conditions flows as far down as an elevation of 1,500 or 2,000 feet. By far the greatest volume of its water is collected from the swamps near the head, and during rainy weather its volume reaches 5,000,000 to 7,000,000 gallons (7.74 to 10.83 cubic feet per second). On June 1, after three or four days of dry weather following showery weather, it was measured at an elevation of 3,160 feet, where its canyon has comparatively slight grade. The flow was 1,300,000 gallons in twenty-four hours (2.01 cubic feet per second). On June 19, after three weeks of hot and dry weather, it measured at the same place 350,000 gallons (0.54 cubic foot per second), at about which figure the flow, according to all accounts, remains constant during the summer, though in exceedingly dry weather it may dwindle as low as 50,000 gallons (0.08 cubic foot per second).

Kamalo Gulch.—This stream, together with the two adjoining gulches to the east, receives the drainage of the swamps of the highest mountain region, and in its general characteristics is very similar to the Kawela, though probably carrying a somewhat larger quantity of water. It usually flows at the mouth of the gulch once or twice a month. It is located on the property of the Kamalo Sugar Company, who use it to some extent for irrigation.

East of Kamalo no detailed observations were made. But, as stated above, the rainfall increases steadily in this direction, and grassy slopes descend far toward the sea. Between this place and Halawa the country is comparatively thickly settled. Little flats are common along the shore and little groups of cocoa palms and taro patches appear at frequent intervals. In this distance there are several streams similar to Kamalo and at least one permanent water course, the Waialua. The gulches are numerous and very closely spaced.

WELLS.

The fact that water can be obtained along the coast by shallow wells was recognized long ago, and irrigation on a small scale by means of windmills has been practiced in many places. Water for stock has been obtained in the same manner.

KALUAKOI.

On the western part of the property (Kaluakoi) precipitation is slight and the supply of ground water is accordingly limited and salty in character.

On the north coast, nearly due north of Mauna Loa, is located the Momomie well and windmill, used for watering stock. Here, as at all of the other stock wells, the surplus water is allowed to run back into the well. The depth is 35 feet, water standing at about sea level 30 feet below the surface. The salinity is very high—238 grains per gal-

lon. One mile eastward is an old landing place, where two small houses are still standing. A well 20 feet deep was dug here, but has been allowed to cave.

There are no wells along the coast west of this until Papohaku is reached, at the middle of the west coast. Several wells have been dug in the sandy plain which here follows the coast for about 1 mile. The well and windmill which supplies the stock is one-half mile southeast of Puu o Kaiaka; the depth is 40 feet, the water level, which is equal to the sea level, standing 35 feet below the surface. The water has a salinity of 403 grains to the gallon, thus closely approaching the limit for drinking purposes, even for stock. A quarter of a mile southwest is a smaller well, which probably stands at 200 grains and which is used by the stock men when stopping at Papohaku.

There is no further water until Kamakaipo, where, on the little plain adjoining the sea, a 30-foot well has been dug, the water standing 10 feet below surface. This well proved too salty for use. A smaller well close by, on the trail, is 10 feet deep and contains a little water which has about 150 grains of salt per gallon.

From the light-house to Palaau along the coast fairly good water is much more abundant and the four following wells and windmills are located here on the sandy shore. Alena well and windmill, 1 mile southeast of Waieli, depth 10 feet, salinity about like Kolo; Kolo well and windmill, 5 miles farther east, 7 feet deep, salinity 126 grains per gallon (Pl. II, *A*); Waiakane well and windmill, south of Mauna Loa, 4 feet deep, salinity 150 grains per gallon; Ioli well and windmill, near Palaau, 6 feet deep, salinity 109 grains per gallon, water stands 2 feet below surface.

PALAAU.

A number of wells have been bored near the coast at Palaau, all of them in the vicinity of the proposed site of the mill of the American Sugar Company.

Well No. 1.—This is a 12-inch well at stable 500 feet south of mill site, at an elevation of 22 feet. It is sunk in basaltic lava to a depth of 74 feet, the water standing at about sea level. The water contains 86 grains of salt per gallon. The well was pumped for four days continuously at the rate of 750,000 gallons (1.16 cubic feet per second) without change in water. It supplied the camp with water pumped up to a tank.

Well No. 2.—This is a 12-inch well below the railroad on west boundary of Hoolohua, at an elevation of 125 feet above sea level. It was sunk in basaltic lava to a depth of 140 feet, the water standing at sea level. The water contained 102 grains of salt per gallon when first struck.

Well No. 3.—This well is one-fourth mile east of stable and 100 feet northeast of deep well, at an elevation of 23 feet. It was sunk through

basaltic lava to sea level. In bottom 12-inch well sunk to 50 feet below sea level; very little water near surface. The water contained 86 grains of salt per gallon. This well was pumped for some time—just how long I was unable to find out; probably two weeks—at the rate of 750,000 gallons a day (1.16 cubic feet per second) without increasing the salinity.

Palaau deep well.—This well is located about one-fourth mile east of stable at Palaau, at an elevation of 22 feet above sea level. Total depth when work stopped, May, 1900, 250 feet. The surface formation was basaltic lava. At 180 feet some red tuff was met; at about 200 feet the rock was a coarse, open lava.

The first water, at sea level, contained 86 grains of salt per gallon; at 174 feet 90 grains were noted; at 180 feet from surface the well broke into salt water, which continued until the work was stopped.

Well in Meyers Gulch.—This is one of the oldest wells bored. It is located in Meyers Gulch, one-half mile above the railroad bridge and 1 mile east of Palaau, at an elevation of 50 feet above sea level. The total depth is 125 feet. Very little water, but of fair quality, was obtained at sea level; at 125 feet the well broke through into sea water.

Wells at mouth of Meyers Gulch.—There are shallow wells on the level plain at mouth of Meyers Gulch, at an elevation but little above sea level. Water stands 2 feet below surface. Water contained 90 grains of salt per gallon.

NAIWA.

The wells on this land are located near the mouth of a small dry gulch, 1½ miles west-northwest of the cocoanut grove. At 37 feet above sea level a shaft 10 by 10 feet is sunk 33 feet close by a 12-inch bore hole sunk to a depth of 70 feet. The first water, which stood at sea level, contained 74 grains of salt per gallon. Deeper, this increased to 90 grains. There is no record of pumping tests.

This locality was selected as repumping station for the high-lift pump intended to elevate the water to the 500-foot level.

KALAMAULA.

On this land, about 1¼ miles northwest of Kaunakakai, are situated the so-called cocoanut grove wells. They are located near the mouth of a little dry gulch, 2,000 feet from the sea, and in the northeast corner of a fine field of arable land which was plowed in 1900 and which it was intended should be planted to cane to be irrigated from these wells. Many good-sized springs come out on the seashore at the cocoanut grove; hence this was probably considered a good location for wells.

Cocoanut grove deep well.—This well is 27 feet above sea level.

Total depth is 343 feet. Diameter is 12 inches. Strata passed through are as follows:

	Feet.
Soil	10
Coral rock	5
Hard lava	25
Porous lava	75
Hard lava	35
Porous lava	193

Water was struck at sea level and contained 80 grains of salt per gallon. At 150 feet the water contained 91 grains, while at 160 feet the bore hole broke through into what was practically sea water and continued in it the whole remaining distance.

Cocoanut grove shallow well.—About 300 feet west of the deep well, at an elevation of 20 feet, is located another 12-inch well, 60 feet deep. One million gallons were pumped during twenty-four hours (1.55 cubic feet per second), the water containing 102 grains per gallon.

Cocoanut grove pits.—Beginning near the above-mentioned well a series of pits have been dug to below sea level. An excavation about 200 feet long and 15 feet deep has been made, and in the bottom of this 10 wells, 8 by 8 feet, have been dug to a depth of 10 feet, though some of them are not yet completed. While there seems to be a considerable quantity of water, no pumping tests have been made, the discouraging feature being that the water coming in ranged from 102 to 104 grains per gallon.

KAUNAKAKAI.

A number of wells have been bored at or near the mouth of Kaunakakai Gulch. Before the advent of the American Sugar Company there were at the mouth of the canyon several shallow wells on the property, on one or two of which windmills were erected. Water of a salinity of about 35 grains was obtained in sufficient quantities for the local needs of the small kulianas at slight depths, about equal to sea level. When undisturbed for some time the water from the upper part of the ground-water sheet contained only 12 grains of salt per gallon. A well at the Japanese hospital at the foot of the lava bluff, 1,000 feet west of the cane-field wells, was sunk to sea level, yielding water which contained 74 grains of salt per gallon.

The deeper wells bored by the American Sugar Company are as follows:

Cane-field wells.—Two wells have been sunk in the cane field from which during the year the 80 acres of cane at Kaunakakai have been irrigated. These wells are situated on the west side of the gulch at an elevation of 22 feet, have a depth of 60± and 75 feet, and are 40 feet apart. Both have a diameter of 12 inches. Water level was

reached after penetrating 22 feet of gravel and soil, the rest of the wells being bored in basaltic lava of varying hardness. Only the 60-foot well is being pumped. A supply of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) has been steadily obtained from it for over one year without increase in salinity, which is from 86 to 96 grains. A sample taken May 4 contained 84 grains. In the summer of 1899, however, the water was somewhat less salty than in 1900, for I find a record of July 10, 1899, showing that after two days of pumping from the first well (No. 1) the water contained 68 to 70 grains of salt per gallon. When the centrifugal pump, which now raises the water from the 60-foot well to an elevation of 40 feet, was connected with both wells the salinity increased to over 100 grains, showing that the deeper well had tapped some salty water.

The settlement well.—This is the most southerly of the long row of wells on the east side of the gulch. The elevation of the ground is 25 feet. The 12-inch well is 60 feet deep. The strata penetrated are largely soil, gravel, and soft lava, and there is, indeed, some doubt whether the bed rock was actually reached. A small pump elevates the water from this well to a tank from which the settlement is supplied. The well has yielded about 200,000 gallons a day (0.31 cubic foot per second) continuously. The water contains from 50 to 86 grains of salt per gallon. A sample on May 4 gave 83 gains; on June 11, 80 grains.

The three upper wells.—These are located on the west side of the gulch, 1,000 feet above the main pumping station and at elevations of 50, 60, and 63 feet. The depth of all of them is about 60 feet, water standing at sea level and containing 74 grains of salt per gallon. Except for a few feet of soil the wells are in lava of varying hardness. These wells have not been tested at all as to their capacity, as their high salinity seemed discouraging.

The deep well.—This well is the most northerly of the long row near the main pumping station. It has a diameter of 12 inches. The total depth at end of May, when discontinued, was 500 feet. The mouth has an elevation of 35 feet. Below 15 feet of gravel followed 25 feet of hard lava, below which porous, ashy, and caving lava was met down to 110 feet; from here to 150 feet followed hard lava, and then a porous stratum down to 250 feet. Below 250 feet hard and soft lava alternate, no special record being kept. The first water at sea level contained 50 grains of salt per gallon; at 160 feet the well broke into salt water, which continued until the work was stopped.

The 12 wells for main pumping station.—All of these are arranged in a row parallel to the bluff, and well No. 7, counted from south to north, has an elevation of 31 feet above mean sea level; from this elevation the other wells differ but little. All of the wells are 60 feet deep, except No. 13, which was known as the "donkey-engine well,"

and which is 75 feet. As in all of the wells bored, the absence of a detailed and reliable record is noticeable. Wells Nos. 7 to 13 reached bed rock at a distance of from 15 to 26 feet, indicating a decided slope southward. Below this only lava was met with, the hardness changing every 15 or 20 feet. In wells Nos. 2 to 6, inclusive, the bed rock was deeper, 26 feet below surface or more, and it is vaguely stated that every well showed a different record. In all wells the water was found at about sea level or, at most, 1 foot above it. The water when first struck contained from 20 to 40 grains of salt per gallon. Wells Nos. 1 to 12 were tested by pumping at the rate of 300,000 or 400,000 gallons in twenty-four hours (0.46 to 0.6184 cubic foot per second) from each for a few hours, the maximum salinity being 40 grains. Only No. 13 was tested somewhat more severely, being pumped four days at the rate of from 500,000 to 750,000 gallons per twenty-four hours (0.77 to 1.16 cubic feet per second). April 5, 1899, a sample from this well contained 11.5 grains of salt per gallon. Pumping at the mentioned rate from May 10 to 13 increased the salinity rapidly to 70 grains, and the last day it reached 83 grains.

After the erection of the 10,000,000-gallon (15.47 cubic feet per second) steam pump to draw from wells Nos. 2 to 13, inclusive, the pumping began in January, 1900. According to Mr. D. Center, at the beginning of the pumping the water contained 50 grains of salt per gallon. The pumps were started at 2,500,000 gallons (3.87 cubic feet per second), and after one week the salt had increased to 110 grains per gallon. After one month it had reached 200 grains and in March 400 grains, though when it went up to the latter figure both pumps were running at a total rate of 5,000,000 gallons (7.74 cubic feet per second). According to Mr. Boller, the engineer in charge, the quantities drawn were larger and for a considerable time varied between 4,000,000 and 5,000,000 gallons (6.19 and 7.74 cubic feet per second).

When it became clear that continued pumping would not bring in fresh water a series of tests were made to find out, if possible, from which wells the salt water came, but the result seemed to indicate that it was derived from all of them. Wells Nos. 2 to 6 seemed to contain better water than the others, the salt amounting to only about 150 grains per gallon. The quantity of water was, however, small, and these wells were easily pumped dry. In whatever way the other wells were arranged the water reached from 270 to 485 grains.

During heavy pumping from wells Nos. 7 to 13 their water level was lowered 1.5 or, at most, 2 feet.

Risdon wells.—These wells, so called because of the intention to erect a 20,000,000-gallon (30.94 cubic feet per second) Risdon pump on them, are located just 1 mile east-southeast of the Kaunakakai wells described above, at the eastern end of the cane fields. There

are twenty 12-inch wells 40 feet apart, located in three rows, which are also 40 feet apart with a northeast direction parallel to the dry creek near the mouth of which they are placed. They are bored at the foot of a low, rocky bluff, at the foot of which, 1,000 feet south of the wells, a strong spring appears. The most southerly well has a surface elevation of 28 feet, and a shaft is sunk from the surface to a depth of 20 feet, the well being bored 40 feet below the bottom of the shaft. Well and shaft penetrated 10 feet of soil, 2 feet of bowlders, 25 feet of hard lava, 23 feet of porous lava, below which again comes hard lava. All of the other wells have similar records. Salinity, 70 grains; water level, 1 foot above sea level. The most southerly well was pumped forty-eight hours at the rate of 750,000 gallons (1.16 cubic feet per second), after which the water contained 68 grains of salt per gallon and the water level was lowered 2 feet.

The other wells were tested by pumping with the deep-well pump at the rate of 300,000 gallons (0.46 cubic foot per second), but only for a short time. Maximum amount of salt, 74 grains per gallon.

KAWELA.

Between the Risdon wells and Onini station but little fresh water appears on the coast, but from the latter point to Kawela the indications favor a larger supply. On the sandy flood plain of the Kawela the kulianas find all the water needed in shallow wells, the level standing 6 inches above sea level. The water contains 3 grains of salt per gallon. During floods in the Kawela the ground water stands 1 or 2 feet higher than usual.

Up to June, 1900, 9 wells of an average depth of 55 feet had been bored at Kawela, all of them along the foot of the lava slope from 2,000 to 4,000 feet east of the creek. A number of kulianas or small holdings, usually owned by natives, are located on the sandy plain of Kawela and extend nearly up to the foot of the bluff.

Well No. 1.—This 14-inch well, started 12 feet above mean sea level, is 46 feet deep. The well passed through the following strata: Soil, 4 feet; hard lava, 10 feet; soft porous lava, 34 feet; hard lava at bottom. A good stream of water was met at 14 feet from surface. Water level stands 10 feet 9 inches below surface, giving the water level an elevation of 1 foot 3 inches above sea level. Water contains 15 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), the amount of salt rose to 25 grains. Subsequently, at the same time as the heavy pumping took place on well No. 3, this well was pumped for three weeks at the rate of 1,250,000 gallons in twenty-four hours (1.93 cubic feet per second), the amount of salt rising to only 37 grains.

Well No. 2.—This 14-inch well is 40 feet east of No. 1, at an eleva-

tion of 12 feet above mean sea level. It is 50 feet deep, and passes through the same rock as No. 1, except that bed rock is at the surface. Water was struck 10 feet below surface, and the level raised to 1 foot below surface (the only instance thus far noted of artesian pressure). On further boring, however, the water level sank to about 2 feet above sea level, showing that some very porous strata had been encountered. Water contained 18 grains of salt per gallon. Pumped at rate of 1,000,000 gallons in twenty-four hours for twelve hours (1.55 cubic feet per second), highest amount of salt was 25 grains per gallon.

Well No. 3.—This 14-inch well is 40 feet east of No. 2, at a surface elevation of 11 feet. The well is 56 feet deep and passes through 2-foot soil, a few feet of porous lava, and then pretty solid lava until 9 feet above bottom, when a porous stratum was met. Water was struck 5 feet below surface, but at 46 feet depth it was easily pumped dry at rate of 1,000,000 gallons per 24 hours (1.55 cubic feet per second). The well was then sunk 10 feet farther, when a large flow of water was encountered. This single well was pumped for thirty days, March 1–30, 1900, at rate of 2,500,000 gallons (3.87 cubic feet per second). The water level was lowered 8 feet and the salinity rose as follows:

Amount of salt in well No. 3.

	Grains per gallon.
March 2	19
March 7	33
March 16	32
March 20	42
March 24	55
March 28	62
March 30	64

On May 16 the water level stood 8 feet 9 inches below surface of ground, or 2 feet 3 inches above sea level.

Well No. 4.—This 14-inch well is 1,080 feet east of No. 3, at an altitude 17 feet above sea level. It is 58 feet deep and passes through the following strata: Soil and gravel 4 to 5 feet, hard lava to 17 feet below surface, where a heavy stream of water was encountered and the water level raised to 13 feet below the surface; then followed a soft streak for 12 to 14 feet, and hard lava was again encountered in the bottom of the hole.

After short pumping with centrifugal pump it was decided to open the water-bearing stratum met 17 feet below the surface.

A pit was excavated about 12 by 24 feet, the longer side being parallel to the coast. The western half was sunk to 8½ feet below the surface, and a double-action two-cylinder 14 by 15 by 10 Worthington pump (strokes 86 per minute) was placed at this level. The eastern half of the pit was sunk deeper. On May 10 it had penetrated 15 feet

of hard but porous and open lava agglomerate. The water level stood 14 feet below the surface while pumping at the rate of 2,500,000 gallons (3.87 cubic feet per second). The water level in the deep-bore hole No. 4, situated in the middle of the western end line of the pit, was 1 foot lower. On May 10 the water from pump contained 37.5 to 40 grains of salt per gallon. Pumping began May 8 at 9 a. m. and continued with some intermissions to June 25, when the pumps were removed to well No. 6.

On May 16 the pit was down to 16 feet from surface, while the water stood 14 feet below, and work was becoming difficult. Pumping at the same rate was continued, the water containing 46 grains of salt per gallon. The water could not be handled with the Worthington pump, so a small centrifugal pump was added. On May 28 both were running with a total capacity of 3,500,000 gallons (5.42 cubic feet per second). Water coming into the big pit on northeast side 5 feet below sea level contained 29.5 grains of salt per gallon, while the discharge from the main pipe ran 40.4 grains, but contained up to 60 or 70 grains after some hours of continuous pumping.

In the first days of June a 2,000,000 gallon (3.40 cubic feet per second) centrifugal pump was substituted for the smaller one and total rate of pumping increased to 4,000,000 or 4,500,000 gallons (6.19 to 6.96 cubic feet per second). The water was discharged into a flume and was conveyed to the pond near the eastern boundary of Kawela. Up to the end of May the 20-inch suction pipe had been allowed to remain in the bore hole drawing up salty water all the time, but then this pipe was first shortened and finally placed in the bottom of the pit. The total depth of the pit from surface of upper (north) side is 18½ feet. Tunnels were now started from the northeast and southwest corners of the pit. On June 8, 2 p. m., pumping 4,000,000 gallons continuously, the water in the northeast tunnel ran 40 grains of salt per gallon, while the water in the flume contained 90 grains. On June 11, pumping continued as before, keeping water within 16 feet of bottom, the heavy stream of water from northeast tunnel ran 35 grains of salt per gallon. Another heavy flow, pouring from the well hole, contained 78 grains. The water in the main discharge flume contained 54 grains; later in the day 82 grains. A big stream of salty water also poured out 1½ feet above bottom of pit in southeast corner; a less amount of same on south side of northeast tunnel but only at its mouth, and still another smaller flow near southwest corner of pit. It had now become apparent that salt water came in from the bore hole and from the south side of the pit near the bottom. A futile attempt was made to check the flow from the bore hole by piling bags filled with earth around it. A week later the well hole was filled with cement, but only to a depth of 20 feet below the bottom of the pit, total depth below it being 40 feet. The pumping was

continued at same rate and the water contained the amount of salt indicated in the following table:

Amount of salt in water from No. 4 well.

[Grains per gallon.]

Date.	Northeast tunnel.	Southwest tunnel.	Flume.	Southeast flow.
June 12	39	27	120	200
13	48	38		
14—9 a. m	48	38	198	341
12 noon	51	52		394
15—2 p. m	57	33		
4 p. m				480
19 [a]	56	65	127	
20—12 noon [b]			125	
4 p. m	45	65	150	225
21 [c]				
22—9 a. m [c]	52	68	110	162
4 p. m	65	48	150	232
23—9 a. m	49	60	111	
4 p. m	52	37	142	232
24 [d]	57	32		
25 [e]				

[a] Pumping stopped for two days.
[b] Running day time only.
[c] June 21 about same as June 20.
[d] No pumping.
[e] Irregular pumping.

All tunnel samples were taken at face.

On this day the tunnel had advanced 32 feet from the pit. The rock, which had been porous and soft, was becoming hard at face, and much water was coming in from the roof. The southwest tunnel had advanced 23 feet in porous rock, but the same was becoming hard, a good stream of water coming in from the floor.

An analysis of above data shows that the two tunnels furnished from 2,250,000 to 2,500,000 gallons (3.48 to 3.87 cubic feet per second) of water, containing on the average 50 grains of salt per gallon, while the southeast flow and the bore hole furnished from 2,000,000 to 2,250,000 gallons (3.10 to 3.48 cubic feet per second), containing from 200 to 400 grains of salt per gallon. Practically all of the salt water comes from these two sources. The rapid increase in salinity from the southeast flow and the bore hole shows that there are leaks in the rocks at these points in almost direct connection with the sea water, while the other parts of the pit had no such connections. It might well have been possible to isolate these sources of contamination.

Well No. 5.—This 14-inch well is located 226 feet east of No. 4, and is 75 feet deep. It passed through the following strata: Soil 3 feet, hard lava to 29 feet from surface, soft red lava tuff to 47 feet from surface, hard lava to 70 feet from surface, soft again from 70 to 75 feet. The water stood 9½ feet below the surface, or 2½ feet above sea level. On May 16 I measured water level to 9 feet 1½ inches below surface. Salinity, 35 grains. Pumped with centrifugal pump at rate of 750,000 gallons (1.16 cubic feet per second) May 8 and 10, but not

continuously. On pumping the level immediately fell 2 feet 3 inches. Highest salinity, 35 grains.

Well No. 6.—This 14-inch well is located 255 feet west of well No. 4 and is 60 feet deep. It passed through the following strata: Soil and gravel with bowlders, 40 feet, remainder lava, in part soft. Water contains 25 grains of salt per gallon. Was pumped two days with well pump (capacity, 300,000 gallons, or 0.46 cubic foot per second). Water stands normally 15 feet 6 inches below surface. Pumped also intermittently from June 11 to June 16 at rate of from 500,000 to 850,000 gallons (0.77 to 1.32 cubic feet per second), the water level only being lowered 3 to 4 inches. On June 16 the water contained 31 grains of salt.

Well No. 7.—This 14-inch well is located 240 feet west of No. 6, and is 59 feet deep. It passed through soil and gravel 30 to 35 feet, below this lava of varying hardness. There were no pumping tests up to June 30 on account of lack of available pumps.

Well No. 8.—This 14-inch well is 240 feet west of No. 7 and has a total depth of 58 feet. There have been no pumping tests.

Well No. 9.—This 14-inch well is 195 feet west of No. 1, at an elevation of 20 feet. Down to some feet below water level hard lava prevails. The well was not finished by end of June. There are no special tests of water from the last three wells, but the amount of salt ranges from about 25 to 35 grains per gallon.

On the west side of Kawela Gulch a shaft was sunk at an elevation of 30 feet in a small side gully. Water containing only 3 grains of salt per gallon was found somewhat above sea level. The water came in too fast for bailing, but no pumps being available nothing further was done at this locality.

Other wells.—Since the middle of May, 1900, a series of six shafts (5 by 5 feet) have been sunk to sea level between the wells, but no pumping has been done on these. It was proposed to extend a tunnel from well No. 4 to well No. 1, a little below sea level; this tunnel was to grade toward No. 1, where a central pumping station was to be located, and was to collect the upper stratum of the ground water, to which that from the deeper strata down to 60 feet was to be added by pumping from the wells. As it was shown, however, that tunneling under existing circumstances was quite difficult at well No. 4, it was intended at the time of my departure from Molokai to substitute an open cut and trench for the tunnel.

THEORETICAL AMOUNT OF WATER AVAILABLE.

The rain falling on the island is disposed of in the three following ways: One relatively small part is evaporated from soil and from plants. A second and large part is absorbed by the soil and, continually moving, sinks down to the surface of permanent saturation, which slopes gently seaward; all of this water finds its way to the shore and must emerge from the rocks at or about sea level. A third

part runs off in the living streams. On the north coast and in the summit region this amount reaches at least one-half of total rainfall, for the ground here contains much water and only slowly absorbs more. Over the south slope the run-off is very small, for the living streams are here largely absorbed before reaching the sea. The run-off of the total south slope is probably only 30 per cent of the total rainfall. It is greater at Kawela than at Kaunakakai.

Absolute data can not be obtained on account of lack of information as to rainfall; but, taking all conditions known on this and adjacent islands, the following approximate calculation may be made:

Total area of south slope from Meyers Creek to east boundary of Kawela is 54 square miles; average rainfall over this area is 4 feet per year; total annual rainfall over this area, 6,048,000,000 cubic feet, or 45,358,000,000 gallons, or 126,000,000 gallons per twenty-four hours (194.95 cubic feet per second); evaporation, 26,000,000 to 36,000,000 gallons (40.23 to 55.70 cubic feet per second); run off, 20,000,000 to 30,000,000 gallons (30.94 to 46.42 cubic feet per second); ground water, 60,000,000 to 80,000,000 gallons (92.83 to 123.78 cubic feet per second). Of this amount it was proposed to secure nearly one-half, or 30,000,000 gallons (46.42 cubic feet per second), at one place near Kaunakakai, which clearly would be impossible.

The ground water available from one-half mile west to 1 mile east of Kaunakakai and from the coast to the summit, including the drainage of Kaunakakai and small gulches to the east, may be roughly calculated as follows:

Area, 36,000 by 12,000 feet; average rainfall over whole area, 4 feet; total amount of water, 1,728,000,000 cubic feet, or 13,000,000,000 gallons per year, or 36,000,000 gallons in twenty-four hours (55.70 cubic feet per second); evaporation, 8,000,000 to 12,000,000 gallons (12.38 to 18.57 cubic feet per second); run off, 5,000,000 to 10,000,000 gallons (7.74 to 15.47 cubic feet per second); available for ground-water circulation, 14,000,000 to 23,000,000 gallons in 24 hours (21.66 to 35.59 cubic feet per second), which amount must emerge along the coast. It is thus seen that a considerable amount of water is available, though it is probably distributed pretty evenly over the distance, and its long passage through the rocks has rendered it salty. The fact that for a whole year 1,000,000 gallons (1.55 cubic feet per second) has been pumped from the cane-field well goes to prove that there must be a fair amount available along the coast.

A considerable amount of ground water is available at Kawela Gulch. Assuming a drainage area of 24,000 by 12,000 feet for the Kawela property and an average rainfall of 5 feet, for the rainfall is decidedly more than over the Kaunakakai drainage area, we obtain 1,440,000,000 cubic feet, or 10,800,000,000 gallons a year, or 30,000,000 gallons a day (46.42 cubic feet per second). Assuming 6,000,000 to 10,000,000 gallons (9.28 to 15.47 cubic feet per second) evaporation, 4,000,000 (6.19 cubic feet per second) run off, 16,000,000 to

20,000,000 (24.76 to 30.94 cubic feet per second) remain for the ground water that may be considered available near Kawela Gulch. While the total supply is not much larger than at Kaunakakai it is more concentrated and the water is less saline, the normal flow averaging about 35 grains, the flood water on top sometimes going as low as 3 grains.

These calculations of the relative quantities at Kaunakakai and Kawela may not quite express the actual conditions, for from the geologic structure it seems very probable that a large part of the ground water from the headwaters of Kaunakakai Gulch finds its way down to Kawela, thus considerably increasing the amount available there.

The ground water probably available at Kamalo may be roughly estimated as follows:

Assuming a drainage area of 20,000 by 10,000 feet and an average precipitation of 5 feet, we obtain a total of 7,500,000,000 gallons a year or 21,000,000 gallons a day (32.49 cubic feet per second), of which the larger part, perhaps 12,000,000 or 15,000,000 (18.57 to 23.21 cubic feet per second), should be available at or near the mouth of the gulches. Several more favorable locations may be selected between Kamalo and Mapulehu which should aggregate 10,000,000 gallons (15.47 cubic feet per second).

Considering now the high region above with a view to ascertaining how much water may be available for an irrigation system collecting the run-off of the area from the head of Kawela to Waihanau, we may approximately calculate as follows:

Total area involved, 32,000 by 4,000 feet; average rainfall, approximately, 8 feet; total amount of water, 1,024 cubic feet or 7,680,000,000 gallons a year, equivalent to 21,300,000 gallons a day (32.96 cubic feet per second). The run-off, which is here at least 50 per cent of total precipitation, would be 10,500,000 gallons (16.25 cubic feet per second).

The drainage area of the upper Waihanau is 10,000 by 2,500 feet, over which a rainfall of 8 feet may be expected. Total water, 200,000,000 cubic feet, or 1,500,000 gallons per annum; it is proposed to collect the entire run-off of this; the amount estimated by stream measurements is 710,000,000, which is a little less than half of the total precipitation.

UTILIZATION OF THE WATER SUPPLY.

The principal problem on Molokai is how to obtain water for irrigation of the 14,000 acres of deep soil situated in the great gap. Another problem is how to obtain water for the irrigation of the smaller coast flats occurring at intervals from Palaau to Mapulehu.

According to the ordinary estimates of sugar planters, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) are needed to irrigate 100 acres of sugar cane. In the opinion of many this is too much, but at that rate 14,000 acres would necessitate 140,000,000

gallons per twenty-four hours (216.61 cubic feet per second). Assuming 1,000 acres of coast flats, 10,000,000 gallons (15.47 cubic feet per second) more would be needed. It is evident that such an amount of water is not available on the island. A certain amount of water can, however, be obtained and it is of interest and importance to attempt to estimate this quantity. Sooner or later the welfare of the island may demand that all possible resources be made available. First of all, the running water at high elevations must be considered. In a few places, as at Kamalo, this water is carried down in steep-grade ditches to irrigate fields at the coast. This plan is probably impracticable in the long run, for these ditches will soon be washed out and there is great loss of water by absorption. If this plan is to be considered, it would be necessary to conduct the water in iron pipes, but the quantity in each place is usually small, so that it would also be an expensive undertaking for the results achieved. Another plan would be to collect the water of the upper region as far east as Kamalo and to carry it by a series of ditches to storage reservoirs above the cane lands. This would be more feasible and such a plan is considered in the following pages. The supply would entail small expense for maintenance. If cemented ditches were used in places the plant would be put on a permanent basis, necessitating no renewal every ten or fifteen years, as is the case with flumes. There is a further source of supply in the ground water along the coast. This can be collected, carried by flumes or cemented ditches to a point near the cane lands, whence it would have to be raised 400 feet by means of a force pump. Few agricultural industries but sugar plantations could bear such a tax, but, as well known, there are many such high-power pumping plants in the islands, especially on Maui. The expense would be still further increased by the necessity of many well plants, for it is certain that no one place will supply a very great quantity of water. There is a possibility of using electric power, which may aid to solve the problem. At any rate, I think it certain that the coast flats could easily be irrigated from wells, which would not necessitate high pumping.

Another point to be considered is the salinity of the waters. The running streams are very pure, but all of the ground water is more or less contaminated by common salt or sodium chloride. There is less of this at Kawela and Kamalo and to the east, but west of Kawela the salinity increases and reaches 90 grains per gallon at Kaunakakai and Palaau. The danger point in using saline water for sugar plantations is stated to be about 100 grains per gallon. Above this the waters become undesirable and their application may spoil the lands, especially if they are low lying.

UTILIZATION OF THE RUNNING STREAMS.

The amount of water which yearly flows to the sea through Meyers, Kaunakakai, and Kawela gulches is not large, though the torrents are

violent while they last. To collect this amount at sea level would be difficult in many respects, and this plan is not to be recommended; nor will it be less difficult to collect the water from the streams while running at elevations of 500 to 1,000 feet. Flumes would be long and expensive, and the long seasons during which they must remain dry would necessarily soon destroy them.

The only place to economically collect the running water is near the summit region. Here the streams are more constant and less torrential; here, also, is the region of heaviest rainfall and largest relative drainage area. In their lower course most of the streams are in box canyons which can not collect a large amount of water.

It may be thought that flumes have been used too extensively in the scheme outlined below, and in some places where the soil is very light ditches may possibly be substituted, but the danger of losing water by leakage is great, though not so great as farther down the slope, and in installing the system tests and measurements should be constantly made to make sure that no avoidable losses take place. During the dry part of the season most of the streams will flow only a small amount, and a few will dry up altogether; there will be enough, however, to keep the flumes from drying and shrinking. It is probably not desirable to go beyond Kamalo Gulch for the purpose of collecting water for the region of the gap. Beyond this point the summit region is very precipitous and the expense of construction and maintenance would be very great.

The system of collection is combined with a system of storage by which part of the waters of the rainy season will be stored for summer use. A number of reservoir sites have been selected and surveyed which, it is believed, will be tight and satisfactory.

Referring to the data given above under "Running streams," the following amounts are believed to be available in the different gulches at elevations given below:

	210 days (Nov. 1–June 1).		60 days (June 1–Aug. 1)	
	Gallons per 24 hours.	Cubic feet per second.	Gallons in 24 hours	Cubic feet per second.
Waihanau	3,250,000	5.02	1,000,000	1.55
Waialeia	300,000	.46	100,000	.15
Waikolu	1,250,000	1.93	300,000	.46
Kahapakai	250,000	.39	150,000	.23
Mokamoka	200,000	.31	100,000	.15
Luahine Fork	200,000	.31	75,000	.12
Kamiloloa	275,000	.43	100,000	.15
Makakupaia	425,000	.66	150,000	.23
West Fork Kawela	200,000	.31	50,000	.08
East Fork Kawela	1,200,000	1.86	300,000	.46
Total	7,550,000	11.68	2,325,000	3.58

This gives a total for two hundred and seventy days of 1,725,000,000 gallons (230,500,000 cubic feet). During the remaining months of the year there will be a varying flow less than 2,000,000 gallons (3.09 cubic feet per second), which may be considered to offset losses by leakage and evaporation. Assuming 500 acres to be irrigated with 5,000,000 gallons a day (7.74 cubic feet per second), or 1,825,000,000 gallons (244,000,000 cubic feet) a year, which amount certainly is ample, a storage capacity of about 577,000,000 gallons (77,000,000 cubic feet) is required in this case to supply about 480 acres with a steady flow of 4,800,000 gallons in twenty-four hours (7.43 cubic feet per second). During part of the winter months the full amount of water is not needed and consequently any increased storage capacity will increase the area which can be irrigated. The water is to be taken out as follows:

Waikolu.—Elevation of dam 3,600 feet; 4,500-foot flume, 2 by 1½ feet; grade 10 feet per mile; capacity 3,000,000 gallons (4.64 cubic feet per second); to cross gap at head of Makakupaia with 2,000 feet of 10-inch riveted pipe, and discharge in Kamiloloa. Probably too much loss of water would result by allowing water to run down into Makakupaia Fork.

Kawela.—Elevation of damming place 3,220 feet; 15,000 feet of flume to Makakupaia Fork; grade 10 feet per mile; capacity 8,000,000 gallons (12.38 cubic feet per second); size 2 by 3 feet; to dump water over edge of canyon into Makakupaia Fork; crosses Onini Gulch in siphon.

Makakupaia.—Elevation of dam 2,650 feet; 17,000 feet to Hunter's cabin; grade 10 feet per mile, dumping water in upper East Fork of Luahine Gulch at elevation of 2,600 feet; capacity 16,000,000 gallons (24.76 cubic feet per second); size 3 by 4 feet; crossing tributary gulches of Kaunakakai Gulch in siphons and receiving tributary flume from Kamiloloa and Waikolu.

Kamiloloa.—Elevation of dam 3,050 feet; 4,500 feet of flume, 2 by 2½ feet carrying; capacity 5,000,000 gallons (7.74 cubic feet per second); sharp grade,

Luahine Fork.—The water from the Makakupaia ditch is dumped into East Fork of Luahine. The latter is dammed at an elevation of 2,350 feet; 9,500 feet of flume to Kahapakai; size 3 by 4 feet; grade 20 feet per mile; capacity 20,000,000 gallons (30.94 cubic feet per second); crossing Mokamoka Fork and West Fork Luahine in siphons, receiving their flows in 2 by 1 foot tributary flumes; dumps at an elevation of 2,300 feet in Kahapakai.

Waialeia.—Damming place at an elevation of 2,760 feet; 4,000-foot flume 14 by 12 inches; 10-foot grade; dumping into Waihanau; capacity 1,000,000 gallons (1.55 cubic feet per second).

Waihanau.—Damming place at an elevation of 2,046 feet; 4,200-foot flume, 2½ by 3 feet; grade 10 feet per mile; capacity 10,000,000 gallons

(15.47 cubic feet per second); 400 feet of tunnel; dumping water into Kahapakai.

Kahapakai.—Damming place at an elevation of 2,000 feet; 3,000-foot flume, 3½ by 4 feet; capacity 30,000,000 gallons (46.42 cubic feet per second); grade 20 feet per mile; dumping into reservoir No. 1 at Meyers Lake.

From reservoir No. 1 there are several ways by which the water can be conducted down to the lower reservoir sites. The simplest would be to let it run down Meyers Creek to an elevation of 1,100 feet, whence it could be taken to the reservoirs in a ditch. This will, however, almost certainly cause large losses, which can not be afforded. A better plan would probably be to let it down to an elevation of 1,600 feet—that is, 300 feet below the reservoir—whence it can be conducted by a sharp-grade flume across the gap below the reservoir and thence to the head of the flat gulch in which the big reservoirs are located. This gulch, it is believed, is fairly tight; at any rate it is worth trying. Should the losses in this gulch be too large it will be necessary to construct a series of ditches at low grade connected with sharp drops which will conduct the water down to the reservoirs. It should be mentioned that all parts of the system are easily accessible. A wagon road extends from Kaunakakai to the gap at Kaohu station above reservoir No. 1; another road is built from Kaunakakai to Waikolu. Still another can be constructed at very slight cost from Kaunakakai by way of Makakupaia station to the headwaters of Makakupaia, and to the edge of the canyon above the West Fork of Kawela. In places the flumes will be difficult to build, but there do not appear to be serious obstacles in any place.

The required storage capacity, 577,000,000 gallons (77,000,000 cubic feet), is to be obtained as follows:

The highest reservoir is known as Meyers Lake, a small natural pond dammed to some extent by Mr. Meyer. It consists of two basins which can readily be dammed to contain 160,000,000 gallons (21,000,000 cubic feet). The elevation is about 1,900 feet. The site is excellent; the ground is evidently very tight and evaporation slight. Considerable wave action may be expected and the main dam must be riprapped and protected by a break water of logs. Abundant and excellent dam material, clayey, decomposed soil close at hand. Large quantities may be loosened by bank blasting. Two different schemes are proposed; if only the lower basin which drains towards Meyers Gulch is utilized, the capacity will be reduced to 91,000,000 gallons (12,000,000 cubic feet). If both basins are utilized they must be connected by a drain or siphon. The upper basin drains toward the north by means of a narrow cut which must be filled by a dam.

Dam No. 2 and No. 3 are natural basins at elevations of about 900 to 1,000 feet, apparently entirely tight and in their present state ready to receive water. They are situated about 2 miles west-north-

west of Meyer's ranch on the broad grassy ridge south of Eleuweuwe Point. They must be emptied by means of siphon pipes or drain tunnels.

Most of the gulches and creeks of the island have a very steep grade. Among the exceptions to this rule are the three gulches discharging on the north coast over the 1,000-foot pali, 2 or 3 miles north of Middle Hill. The water courses are from 2 to 4 miles long and meander with relatively low grade through the grassy rolling country here continuing out to the very edge of the pali. Their valleys are from about 100 feet deep up to 800 feet wide; their sides, as a rule, grassy and covered by clayey soil. Receiving but little precipitation they contain but little water, even during heavy rains and are thus excellently adapted for storage. Water can be stored in all three at elevation of from 800 to 1,000 feet. The most southerly of these creeks, flowing just south of Eleuweuwe Point, is best adapted for reservoir sites. There is no difficulty in carrying the stored water out from the reservoirs and down toward the cane lands. Four reservoirs were planned on this creek, though one of these, No. 5, may be dispensed with as the desired capacity is obtained without it. The dams must be carefully constructed of the abundantly available clayey soil, and I believe that the reservoirs will be found water-tight. They are calculated to 10 feet on top with a slope of 3:1 on both sides The surveys for these dams were made for me by Mr. E. Pope, at that time one of the surveyors of the American Sugar Company.

List of reservoirs.

No.	Capacity.		Height of dam.
	Gallons.	*Cubic feet.*	*Feet.*
1 (Meyers Lake)	160,000,000	21,389,000	30
2	62,000,000	8,288,000	([a])
3	73,000,000	9,758,500	([a])
4	117,000,000	15,640,500	54
5	138,000,000	18,448,000	54
6	189,000,000	25,266,000	54
7	100,000,000	13,368,000	52
Total	839,000,000	112,158,000	

[a] Natural basin.

From the reservoirs at an elevation of 800 feet the water is easily conducted by ditches and drops in shallow ravines to an elevation of 450 feet, the height of the gap, whence it can be applied to any part of the cane lands desired. The distance from the reservoirs to the cane lands is from 2 to 4 miles. It is easily understood that it is not necessary to construct this whole system outlined above at once. The Waihanau, Waialeia, Kahapahai may be first utilized together with reservoirs No. 1 and No. 2 or No. 7. The results of this system, which will irrigate at least 175 acres, will indicate the success to be expected from the installation of the whole system.

In conclusion it may be estimated that collecting and storing the running streams as outlined above will cost about $120,000 and the water collected amounts to a steady supply of nearly 5,000,000 gallons a day (7.74 cubic feet per second) during the whole year. The utilization of this water will interfere but little with the supply to be expected from pumps at sea level.

If it were found practicable to use the lands for cultivation of fruit trees and vines, this quantity of water—5,000,000 gallons in twenty-four hours (7.74 cubic feet per second)—would easily be sufficient to irrigate 1,000 acres. In view of the strong winds prevalent over the area containing good soil such culture may, however, be difficult. Experiments in this direction would be desirable.

In order to develop the water supply by catching some of the underground flow which otherwise would come out at elevations lower than the point of collection, tunnels might be driven at Waihauau, Waialeia, and Waikolu into the hill perpendicularly to the direction of the drainage, just above the damming place and in both directions from the creek; it is rather probable that notable amounts will thus be collected by comparatively short tunnels, say 100 or 200 feet in length.

Similar tunnels at the places where Kawela and Makakupaia forks are caught are not advisable.

Wailau and Pelekunu.—Referring to previous pages, it is estimated that Wailau has a minimum flow of 8,000,000 gallons (12.38 cubic feet per second) and Pelekunu of 7,000,000 gallons (10.83 cubic feet per second), both at an elevation of 600 feet; but measurements during the driest time of the year are necessary to confirm these figures. Only the minimum supply can be considered, for the high-level irrigation system proposed above has exhausted the greater part of storage capacity available.

The utilization of the water supply of these streams involves (1) a high-level ditch reaching the cane lands at an elevation of 450 feet and (2) long tunnels to bring the water to the south side of the island, the northern coast being entirely impracticable. Both ditch and tunnel will be very expensive.

There are two possibilities: (1) Utilization of Wailau alone; (2) utilization of Pelekunu and Wailau.

By the utilization of Wailau alone 8,000,000 gallons (12.38 cubic feet per second) of water will be obtained, and to this must be added water which will be found in the tunnel. The latter quantity is very doubtful, but will probably amount to several million gallons. The tunnel will tap Wailau, West Fork, at an elevation of 670 feet. The water from the East Fork will be added by ditch across gap south of Puu o Wailau. Length of tunnel to point in the canyon 1¼ miles above Dr. Morritz's house at Mapulehu (elevation 660 feet), 12,800 feet. From Mapulehu to the cane fields there will be 17 miles of conduit and flume,

with many siphons, the latter causing considerable loss of grade. Elevation of flume at cane fields, 450 feet. The expense of this undertaking would probably exceed $400,000. But it should be remembered that there are many things which may cause increased expense. Among these are the possibility that the tunnel may partly or wholly need cementing in order to become tight. Further, that loose strata may be met, which may largely increase the expense. Further, the difficulty of working the tunnel from both ends on account of descending grade and large quantity of water probably met with. Lastly, the difficulty of landing coal and machinery at Wailau. Time needed, if only worked from one end, three years.

By the utilization of Pelekunu and Wailau 14,000,000 gallons (21.66 cubit feet per second) should be secured, besides the large flow which will almost certainly be met in the tunnels. Ditches and flumes must be correspondingly enlarged, and a tunnel 14,500 feet long driven from Pelekunu to convey the water after it is collected from the different branches. The expense would be at least $800,000.

By tunneling the range from Kawela to Pelekunu the long and difficult conduit from Mapulehu to Kawela would be avoided and there would be also considerable saving of grade. The tunnel from Wailau (elevation 650 feet) to Pelekunu (elevation 635 feet) would be 15,000 feet long, while the tunnel from Pelekunu (elevation 635 feet) to Kawela (elevation 610 feet) would be 26,500 feet. All of the previously stated objections apply with still greater force. The enterprise would consume several years and require at least $1,200,000.

In conclusion, I consider it feasible to bring the water from Wailau and Pelekunu to the cane fields, but do not believe that the enterprise would be a paying investment.

UTILIZATION OF THE GROUND WATER.

This plan contemplates the pumping of water from shallow wells at suitable places along the coast up to a low flume, say 50 to 75 feet above sea level, and the further raising of it up to a level of 300 to 500 feet by means of reciprocating pumps. Considering the conditions fully outlined above, it is clear that a large volume of water, say 30,000,000 gallons (46.42 cubic feet per second), is not obtainable in any one place. The only way is to utilize all the resources as far as possible and to collect the water wherever found. It is true that this may be somewhat more expensive than if the water were found in one place, but it is the only plan possible, except if the supply from Wailau and Pelekunu be used.

When the ground water is concentrated about sea level, trenches, pits, or tunnels may offer the best means of collecting the same, the trenches and tunnels as a matter of course being extended parallel to the shore. Even in this case difficulties may occur, for the heavy pumping necessary to prosecute the work is apt to bring in sea water,

and leaks may be found which will admit large quantities of the same. If the water is more evenly distributed through the strata down to 30 or 40 feet below sea level, or if the bulk of it is found at the latter depth, sinking and tunneling become impracticable, for if it is attempted to keep the workings dry, the sea water, being under heavy pressure, is almost sure to find its way in. In such case groups of 14-inch bore holes should be used, and even when the water occurs at sea level they may become preferable. In these porous rocks the capacity of a single bore hole may be comparatively great and amount up to 1,000,000 gallons in twenty-four hours. There is great temptation to overdraw the capacity of wells, and this has been done both at Kaunakakai and at Kawela. Just as soon as a steady increase in salinity is noted the quantity drawn must be decreased. In these rocks one well has a large suction area. If one well will give 1,000,000 gallons (1.55 cubit feet per second), 20 wells surrounding it, say at the corners of each 40 feet square, will probably give at most 3,000,000 to 4,000,000 gallons (4.64 to 6.19 cubic feet per second). While many of these conditions seem discouraging, it should be borne in mind that one single well, that at Kaunakakai, has for over one year furnished a steady flow of water with a salinity of 85–90 grains per gallon, and that many similar places can doubtless be found along the coast.

At Palaau.—According to the data given above (wells and springs) there is probably a considerable amount of ground water available at Palaau at a depth of about 80 feet—how much is difficult to say; there is at least 1,000,000 gallons, possibly as much as 3,000,000. The wells bored have not been adequately tested, and this should first of all be done with the well and shaft near the deep well. If this will yield a steady stream for about a month or two of from 750,000 to 1,000,000 gallons (1.16 to 1.55 cubic feet per second) in dry season, I recommend that two or three more wells be sunk parallel to the coast, about 40 feet apart. If it should be found that these would yield 2,000,000 or 2,500,000 gallons (3.09 to 3.87 cubic feet per second) of water containing less than 100 grains of salt per gallon, this should be utilized to irrigate the bottom lands at Palaau, as well as part of the slopes above, which, though rocky, can be cleared and planted. About 1 mile of small flume will be needed. If the water is elevated to 100 feet by a reciprocating pump driven by electricity, it would require 44 horsepower, or 52 horsepower delivered at the motor. The salinity would be high—i. e., about 90 grains per gallon—and this may in the long run interfere with its use on the lowlands.

Cocoanut grove wells.—The 60-foot well at this place should be tested, which has not been done up to date. Should it be found that this well, with or without adjacent pit, will furnish 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second) of salinity of 100 grains, this water may be used to irrigate the bottom lands adjacent, amount-

ing to 150 acres, less water being needed on these low-lying lands than on the higher ground. This would require 8 theoretical horsepower, or 10 delivered at the motor if electric power be used. Should the water prove too salt, water from Kaunakakai must be used.

Kaunakakai.—One well at Kaunakakai is clearly proved to be able to deliver a steady stream of 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second). It is probable that 2,000,000 gallons (3.09 cubic feet per second) more may be obtained from shallow wells to sea level between this well and the so-called Risdon wells, 1 mile eastward.

Risdon wells.—These 20 wells have never been adequately tested, and their capacity is in doubt. Such incomplete tests as have been made are encouraging, and the conditions seem to indicate that they may furnish 2,000,000 gallons of water (3.09 cubic feet per second) at 80 grains of salinity. The water is contained in a well-defined stratum of porous rock from 9 feet to 34 feet below sea level.

Kawela.—Between Risdon station and the west boundary of Kawela the ground water does not appear along the coast in notable quantities, and the prospect of obtaining water from wells is not encouraging. But one-fourth of a mile east of Onini station very large springs appear on the beach, and I believe that there is 2,000,000 gallons (3.09 cubic feet per second) of ground water available at this place. The wells should be sunk at the foot of the bluff, just east of the rock point which extends to the sea. Preliminary exploration by means of pits or shafts would be necessary to decide at what level the water will be found: possibly most of it is held above sea level, but this is a point which can not be decided at present.

On the west side of Kawela Gulch for a distance of 2,000 feet from the creek a considerable amount of water is probably available. I think 3,000,000 gallons (4.64 cubic feet per second) can be secured here, but whether at sea level or 30 or 40 feet below it is impossible to say at present.

The flood plain of Kawela Gulch at present contains much water in its gravelly bed, but this amount will probably be notably diminished by the diversion of its headwaters into the irrigation system as proposed above. Nearly all of the recent well boring and pumping has been done on the east side of Kawela Gulch. The total quantity of water proved seems to be 4,500,000 gallons (6.96 cubic feet per second). Of this, 2,000,000 gallons (3.09 cubic feet per second) of 40 grains salinity have been shown to be available at wells Nos. 1, 2, and 3; 2,500,000 gallons (3.87 cubic feet per second) of 60 grains salinity may be considered proved at well No. 4, with its pit and tunnels, if the flow of salt water is shut off, which probably can be done by filling the salty bore hole with cement and constructing a cement wall around the leak in the southeast corner of the pit (see p. 44).

Tunneling at about 4 feet below water level has proved a difficult undertaking, and will become more so in the loose gravelly material which will be encountered near wells Nos. 6, 7, and 8. It would probably be better to run an open cut 6 feet wide in the bottom and 4 feet below water level in a line of about 15 feet south of the wells, thus collecting all of the ground water available at sea level into one central station, whence the water could be pumped. But to this must be added such amounts of the ground water as is stored in lower strata, as, for instance, 55 feet below the surface at well No. 3. This deeper water may be secured by connecting the bore holes with the main cut at its level—i. e., 4 feet below the sea level—but each bore hole must first be very carefully tested as to capacity and lowering of water level. If necessary, the open cut must be extended west of well No. 1, and a tunnel run through the bluff of well No. 9. It is almost impossible to outline a plan which in its details can be strictly adhered to, for the conditions change almost from day to day and the work requires the personal supervision of a very skilled and experienced engineer. In conclusion, it is believed that 10,000,000 gallons (15.47 cubic feet per second) may be expected at Kawela, east of the creek, and 3,000,000 gallons (4.64 cubic feet per second) west of the same. At Kamalo a quantity of water almost equal to that at Kawela may be expected, and a few million gallons may doubtless be obtained at intervals between Kamalo and Mapulehu.

To collect these waters will doubtless prove an expensive undertaking, owing to the many small pumping stations. Should it be desired to pump a smaller quantity for purposes of irrigation along the coast, some of the small streams at high elevations could be used to generate electric power to drive the pumps below.

Recapitulation.—While the estimate of waters available below the surface is necessarily very uncertain and difficult, I should place the probable amounts as follows:

Probable amount of water available.

	Million gallons per 24 hours.	Cubic feet per second.
Palaau	3	4.64
Cocoanut grove wells	1.5	2.32
Kaunakakai	3	4.64
Risdon wells	2	3.09
Onini Station	2	3.09
Kawela (west)	3	4.64
Kawela (east)	10	15.47
High-level irrigation system	4.8	7.43
Total	29.3	45.32

ELECTRIC POWER AVAILABLE.

As stated before, the irrigation system from the running streams outlined above should furnish at an elevation of 800 feet a steady supply of 4,800,000 gallons a day (7.43 cubic feet per second), or 3,333 gallons a minute. If the water is applied below 425 feet on the south slope of the gap, 375 feet of fall will be available, giving a theoretical horsepower of 314, which if converted into electrical power by means of Pelton wheel and dynamo and transmitted with high potential to Kawela should be sufficient to raise 13,000,000 gallons 66 feet; length of pressure pipe, 15,000 feet; length of transmission to Kawela, 10 miles. The greatest item of cost is the pressure pipe, which should be 14 inches in diameter, riveted, and of wrought iron, and which would not cost less than $50,000. The transmission would offer no difficulties, nor would the loss in transmission with high voltage be large. The great cost of pressure pipe diminishes the value of this proposition. More electric power could be obtained by utilizing the upper reservoir, which has a capacity of 160,000,000 gallons (247.56 cubic feet per second). Quantity of water available, 1,000,000 gallons per twenty-four hours (1.55 cubic feet per second), or 700 gallons per minute; fall available, 700 feet; total theoretical horsepower available, 123; horsepower available at pumps 5 to 10 miles distant, 75. Pressure pipe from reservoir to power station in Meyers Gulch, at elevation of 1,100 feet, would be 10,000 feet long; diameter of 8 inches should be sufficient. Here, again, the pressure pipe forms the principal item of cost, being not less than $15,000.

This proposition is more favorable, but still very expensive in comparison with the advantages obtained. On the whole, it seems more advisable to depend upon steam for motive power.

Electric power from Pelekunu, Wailau, and Halawa.—According to a preliminary report by Mr. M. M. O'Shaughnessy, dated December 5, 1899, the following approximate power could be generated by utilizing these streams:

Stream.	Normal flow (gallons per 24 hours).	Cubic feet per second.	Fall available for power	Horsepower (theoretical).
Halawa	5,000,000	7.74	300	263
Wailau	10,000,000	15.47	400	701
Pelekunu	5,000,000	7.74	200	210
Waikolu	3,850,000	5.96	.....	.....

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UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON

ARTESIAN BASINS

IN

SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON

BY

ISRAEL C. RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topography Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Bulletins, Professional Papers, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports. Complete lists of papers relating to water supply and allied subjects follow. (B=Bulletin, PP=Professional Paper, WS=Water-Supply Paper.)

Series I—Irrigation.

WS 2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. and maps.
WS 5. Irrigation practice on the Great Plains, by E. B. Cowgill. 1897. 39 pp., 11 pls.
WS 9. Irrigation near Greeley, Colo., by David Boyd. 1897. 90 pp., 21 pls.
WS 10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 51 pp., 11 pls.
WS 13. Irrigation systems in Texas, by W. F. Hutson. 1898. 68 pp., 10 pls.
WS 17. Irrigation near Bakersfield, Cal., by C. E. Grunsky. 1898. 96 pp., 16 pls.
WS 18. Irrigation near Fresno, Cal., by C. E. Grunsky. 1898. 94 pp., 14 pls.
WS 19. Irrigation near Merced, Cal., by C. E. Grunsky. 1899. 59 pp., 11 pls.
WS 23. Water-right problems of Bighorn Mountains, by Elwood Mead. 1899. 62 pp., 7 pls.
WS 32. Water resources of Porto Rico, by H. M. Wilson. 1899. 48 pp., 17 pls. and maps.
WS 43. Conveyance of water in irrigation canals, flumes, and pipes, by Samuel Fortier. 1901. 86 pp., 15 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles, Wyoming, by G. I. Adams. 1902. 50 pp., 11 pls.
WS 71. Irrigation systems of Texas, by T. U. Taylor. 1902. 137 pp., 9 pls.
WS 74. Water resources of the State of Colorado, by A. L. Fellows. 1900. 151 pp., 14 pls.

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Part II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Part III.

Series J—Water Storage.

WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
WS 40. The Austin dam, by Thomas U. Taylor. 1900. 51 pp., 16 pls.
WS 45. Water storage on Cache Creek, California, by A. E. Chandler. 1901. 48 pp., 10 pls.
WS 46. Physical characteristics of Kern River, California, by F. H. Olmsted, and Reconnaissance of Yuba River, California, by Marsden Manson. 1901. 57 pp., 8 pls.
WS 58. Storage of water on Kings River, California, by John B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Part IV.

Series K—Pumping Water.

WS 1. Pumping water for irrigation, by Herbert M. Wilson. 1896. 57 pp., 9 pls.
WS 8. Windmills for irrigation, by E. C. Murphy. 1897. 49 pp., 8 pls.
WS 14. New tests of certain pumps and water lifts used in irrigation, by Ozni P. Hood. 1898. 91 pp., 1 pl.
WS 20. Experiments with windmills, by T. O. Perry. 1899. 97 pp., 12 pls.
WS 29. Wells and windmills in Nebraska, by E. H. Barbour. 1899. 85 pp., 27 pls.
WS 41. The windmill; its efficiency and economic use, Part I, by E. C. Murphy. 1901. 72 pp., 14 pls.
WS 42. The windmill, Part II (continuation of No. 41). 1901. 73-147 pp., 15-16 pls.

(Continued on third page of cover.)

Water-Supply and Irrigation Paper No. 78

Series { B, Descriptive Geology, 29
{ O, Underground Waters, 20

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

PRELIMINARY REPORT

ON

ARTESIAN BASINS

IN

SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON

BY

ISRAEL C. RUSSELL

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, D. C., December 2, 1902.

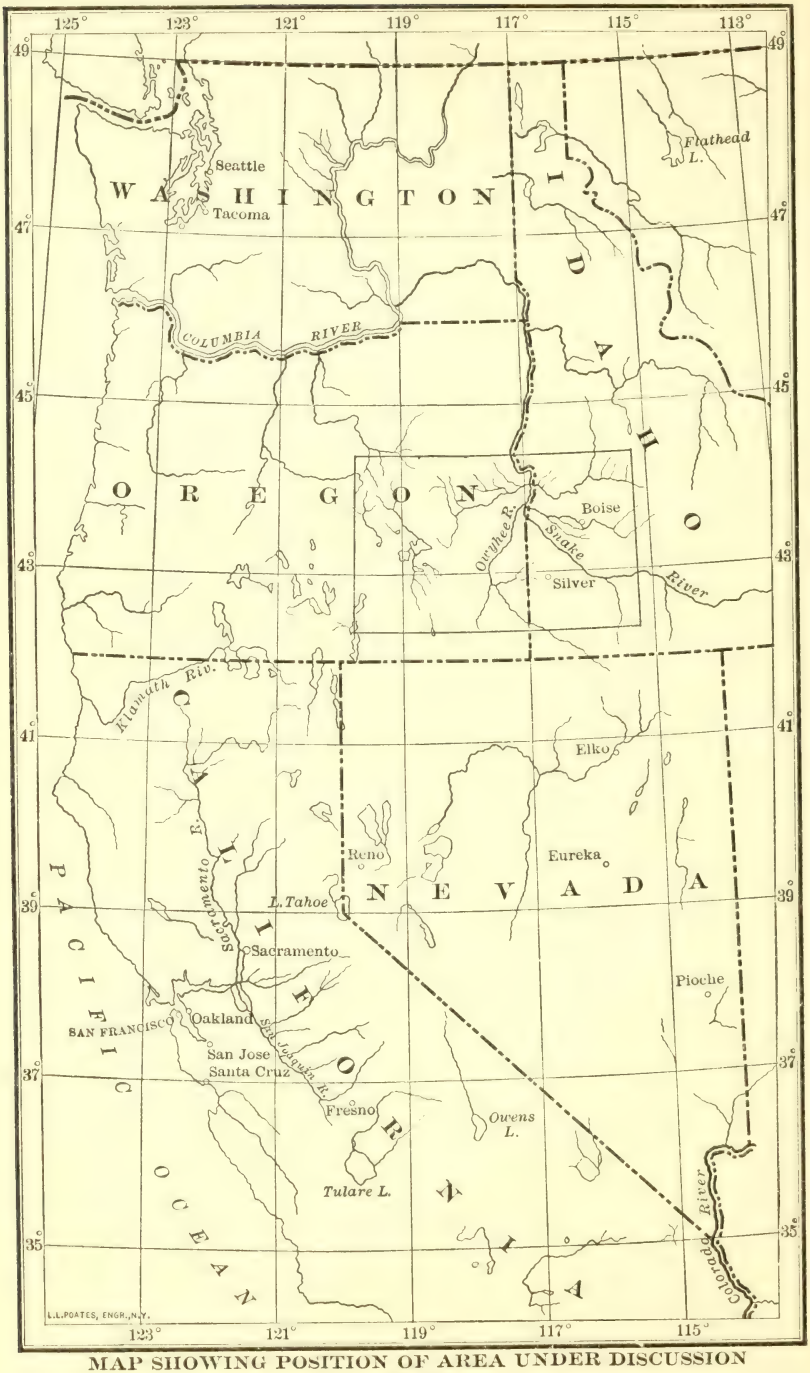
SIR: I have the honor to transmit herewith a manuscript prepared by Prof. Israel C. Russell, and to request that it be printed as one of the series of Water-Supply and Irrigation Papers. The paper relates to work carried on by Professor Russell during the summers of 1901 and 1902, and contains a description of the geologic structure of southwestern Idaho and southeastern Oregon, with special reference to the occurrence of underground waters. The artesian basins are described as far as these are known, and facts are assembled as to the probabilities of obtaining deep or flowing wells.

The information has particular value at this time, when great interest is being displayed in the reclamation of the arid lands. All facts which assist in procuring water are eagerly sought, and the data collected by Professor Russell are particularly important in the development of a large extent of vacant public land.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



MAP SHOWING POSITION OF AREA UNDER DISCUSSION

Scale

100 50 0 100 200 300 miles

PRELIMINARY REPORT ON ARTESIAN BASINS IN SOUTHWESTERN IDAHO AND SOUTHEASTERN OREGON.

By Israel C. Russell.

INTRODUCTION.

During the summer of 1901 I made a geological reconnaissance in southern Idaho which covered, in a general way, the region embraced in the Snake River Plains from the boundary between Ada and Elmore counties eastward to Blackfoot.[a] The studies thus begun were continued in the summer of 1902, when parts of Canyon and Owyhee counties, Idaho, and of Malheur and Harney counties, Oreg., were examined. The route traversed during the second reconnaissance followed Snake River from Guffey northwestward to the mouth of Owyhee River, in Idaho, and thence through Vale, Westfall, Beulah, Drewsey, Harney, Burns, Narrows, Diamond, Smith, Mule, Alvord Valley, Jordan Valley, etc., in Oregon, to Rockville, on the west border of Owyhee County, Idaho. From Rockville the return to Boise was by way of Caldwell and Nampa. The route followed was chosen for the purpose of passing through the greatest number of valleys where artesian conditions might most reasonably be expected to exist and where the largest areas of good land are available for agriculture.

Each of the journeys referred to above was a rapid reconnaissance, having for its principal object the discovery of localities where flowing water can be obtained by drilling wells. In addition to gathering facts bearing on the question of an artesian water supply, as much attention as the time available would permit was given to the study of the general geology of the country traversed, the surface water supply, soil conditions, etc. The results of my examinations may, then, be divided into two parts—namely, that pertaining directly to artesian basins and that relating to geological history, topographical development, etc. As the search for artesian basins, especially during the journey made in 1902, was far more successful than I had hoped, it

[a] A report on this reconnaissance, entitled Geology and Water Resources of the Snake River Plains of Idaho, has been published as Bulletin No. 199 by the United States Geological Survey. A copy of this report may be had without charge by applying to the Director of the United States Geological Survey, Washington, D. C.

seems advisable to present a preliminary report, with the view of giving early information concerning the artesian basins to the people living in the region examined and later to prepare a more definite record of the geological and geographical facts observed.

During the reconnaissance of 1901 it was found that the geological conditions in the Snake River Canyon from near Glenns Ferry westward to the boundary between Elmore and Ada counties and in Bruneau and Little valleys are such that a surface flow of water can reasonably be expected where the surface elevation is not too great if wells are drilled to the proper depth. The artesian basin crossed by the portion of Snake River just mentioned was for convenience named the Lewis artesian basin, but its extension west of the boundary between Elmore and Ada counties was not examined. The western portion of the basin was made the first subject of study during the following field season, and, as will be stated later, it was found to reach westward to beyond the Idaho-Oregon boundary.

The reconnaissance in southeastern Oregon showed that if wells are properly drilled, a surface flow of water may reasonably be expected in at least three separate valleys in addition to the basin which is crossed by Snake River. These are Otis Valley, situated about 6 miles north of Drewsey; the broad valley in which Malheur and Harney lakes are situated, known in part as Harney Valley; and Whitehorse Valley, situated about 10 miles east of the higher portion of Stein Mountain. The basins in which these valleys are situated will be termed in this report the Otis artesian basin, the Harney artesian basin, and the Whitehorse artesian basin, respectively.

Before presenting the facts which are the basis of the conclusion that in each of the basins just named a surface flow of water can be had by drilling, it will, I think, be of assistance to review briefly the leading conditions governing the flow of artesian wells.

CONDITIONS ON WHICH THE FLOW OF ARTESIAN WELLS DEPENDS.

The term artesian well, as commonly employed, signifies a well which overflows upon the surface. The leading conditions favoring the rise and overflow of water from wells may perhaps be best indicated by describing the essential features of a typical artesian basin of the simplest character.

In what is properly termed an artesian basin, the layers of rock are bent downward, so as to resemble a pile of shallow plate-shaped dishes, placed one within another. One or more of the beds of rock is porous and allows water, supplied by rain on its upturned and exposed margin, to percolate into it. Above and below the water-charged layer are close-textured beds, like clay, which prevent the escape of the water in the bed between them. The leading conditions

which characterize artesian basins will be reproduced on a small scale if one pan is placed within another, and the two are separated by a layer of sand, and the spaces between the sand grains are filled with water. If a hole is drilled in the bottom of the uppermost pan, water will rise from below and overflow until the level of the water in each pan is the same. This is illustrated by the following cross section (fig. 1), which represents two pans, with a layer of sand between them, as they would appear if cut across and one-half removed. The pans in such an experiment represent the compact or impervious layers, and the sand the porous or pervious bed, in an artesian basin.

FIG. 1.—Cross section of two dishes with layer of sand between; to illustrate the leading essential features of an artesian basin.

In the following diagram (fig. 2) an ideal cross section is presented through an artesian basin which may be assumed to be 50 or more miles in diameter. The rocks are in layers or strata, and their combined thickness, we will assume, is 1,000 feet. A cross section taken in any direction through the pile of saucer-shaped beds (as is the case with the experiment with the pans referred to above) would be essentially the same. In the diagram (fig. 2) B and C represent compact and impervious beds, such as clay or shale; and A represents a porous bed, such as sand, open-textured sandstone, or fissured and broken rock. The beds, it will be noted, are depressed in their central parts, but about their edges come to the surface. Under these conditions water falling as rain on the exposed margin of the pervious bed and the water from streams, etc., would percolate into it until it was water filled. If, now, a hole drilled in the central part of the

FIG. 2.—Ideal section illustrating the chief conditions requisite to artesian wells.

basin, as at D or E, reaches the pervious bed the pressure of water at a higher level will cause the water in the well to rise and overflow at the surface, and a flowing artesian well will result.

If, in the case just cited, no additional water should come to the exposed margin of the pervious bed, the well drilled at D or E would decrease in volume and finally cease to flow when the water in the porous bed, or so-called reservoir, was lowered so as to be on a level with the surface at the localities referred to. If, on the other hand, rain falls on the exposed margin of the pervious layer, or streams bring water to it, a continuous discharge from the well would result; as will be seen, one well in an artesian basin might be conspicuously

successful, while many wells might permit of such a freedom of escape of the water in a pervious bed as to practically ruin all of them.

In the illustration just presented, but one pervious bed was considered. In nature several such beds may be present in a single artesian basin, and several wells, drilled to different depths, might be successful, each well being supplied by a different pervious bed.

The height to which the water will rise above the surface opening of an artesian well depends on the height of the water in the raised border of the water-charged bed from which it derives its supply. For example, in fig. 2 the lowest point in the rim of the water-charged bed is at A, and if the pipe in the well drilled at D or E be carried up into the air and the end not closed, the water will rise in it until it reaches the level of A. The height to which the water will rise in an open tube attached to the surface opening of an artesian well is termed the artesian head. At all points within an artesian basin below the level of the artesian head water may be expected to rise to the surface and overflow when a well is drilled and properly cased. But if the surface of the ground is above the horizon of the outcrop of water-bearing bed, the pressure on the water will not be sufficient to force it to the surface, even if a drill hole is put down and properly cased. The height of the surface within an artesian basin may thus furnish the controlling condition on which success in searching for artesian water would depend. For this reason the pioneer well in an artesian basin should evidently be drilled at the lowest available locality in order to determine the artesian head. In making this test the bottom of the casing in the well should be just above the water-bearing stratum and securely packed on the outside so as to prevent leakage. If a well has a surface flow the height to which the water will rise above the ground may be learned by attaching a flexible hose pipe, or, in fact, any kind of a tube, to the upper end of the casing of the well and carrying it up a ladder or trestle until the water stands at the upper end, but does not overflow.[a] When two or more water-charged layers are present in an artesian basin, wells obtaining water from different layers may have different artesian heads.

Another necessary surface condition in reference to most artesian basins is that the margins of the porous beds shall rise to the surface and be exposed, so as to become charged with water from rain, melting snow, streams, etc. The amount of precipitation is also an important factor, especially in reference to the number of wells that may advantageously be put down in an artesian basin; but even in regions having an arid climate the porous beds beneath the surface so situated as to receive water at their edges, and from which its escape is prevented, will be found to be water charged.

As the pervious beds in an artesian basin commonly descend to a

[a] Practical suggestions in this connection are presented in the papers No. 3 and No. 4 in the list at the end of this report.

considerable depth below the earth's surface, the water which escapes from them when drill holes are put down is usually warmer than the water in neighboring dug wells. The reason for this is that the temperature of the earth increases with depth below its surface, as is discussed below. The temperature of water in a pervious bed is therefore regulated by the depth of the bed below the surface, and several flowing wells drilled in the central part of a basin should yield water with essentially the same temperature.

In the case of artesian basins generally, the water supply is furnished by rain and streams and enters the pervious beds at their outcrops—that is, the water descends into the pervious beds from above. There are instances, however, in which the water rises from below. If a basin exists, as already explained, water may be supplied to the pervious beds either by the upward leakage of a lower pervious bed, or, as is illustrated in the following diagram, by fissures in the rocks beneath.

The water which rises through deep fissures in the earth's crust is commonly hot, and when it appears at the surface forms hot springs. In a case like that illustrated by fig. 3 the pervious bed is charged by

FIG. 3.—Ideal section of an artesian basin charged with water rising from below through a fissure.

water rising through the rocks beneath it, and artesian wells supplied by it would have a higher temperature than under normal conditions would be expected from their depth. More than this, several wells drilled in the central portion of a basin which is supplied in the manner just explained might vary greatly in temperature according to their distance from the subterranean source of supply, although deriving their water from the same pervious bed. The artesian head in the case just cited would depend on the height of the water stored in the pervious bed, but could not exceed the pressure on the incoming water from a deep source. Where there is a subterranean source of water supply for an artesian basin there is probably always an additional supply coming from above, so that both the pressure and temperature of the water obtained by drilling will be regulated by an adjustment between these two leading conditions.

There are other conditions than those just considered which permit a surface flow of water when wells are drilled, but so far as the artesian basins to be described later are concerned, it is unnecessary to consider them at this time.

Even when a well-defined artesian basin is present there may be qualifying or adverse conditions which will prevent a surface flow of

water where one might reasonably be expected. These "accidents," as they may perhaps be termed, are caused by the fact that sheets of rock which are open textured, and consequently pervious, in one portion may become close textured and practically impervious in another portion. Also, an impervious bed may be fractured so as to allow the water to escape. In Idaho and Oregon the rocks which are bent so as to form basins are at times traversed by dikes; that is, more or less vertical sheets of rock formed by molten material forced upward into fissures from deep within the earth's crust, and cooling and hardening. There are still other locally adverse circumstances which may exist in even the best-defined artesian basins. These and other questions bearing on the success or failure of artesian wells have been discussed by several writers, and for a more complete and critical presentation of the subject than it is desirable to attempt at this time the reader is referred to the publications mentioned at the end of this report.

SURFACE INDICATIONS OF THE PRESENCE OF SUBSURFACE WATER UNDER PRESSURE.

The presence of artesian conditions is most frequently inferred from the structure of a basin, but confirmation of the supposition that water under pressure exists below the surface may frequently be had from the occurrence of warm springs. Such springs may also furnish evidence in reference to the depth to which a well should be drilled in order to penetrate the water-charged stratum.

The water which occurs in artesian basins has descended from the surface, and as the temperature of the earth increases with depth, the deeper the water has penetrated the rocks the higher will be its temperature. The increase in the temperature of the earth below a depth of about 50 feet in temperate regions is in general about 1° F. for each 60 feet, but there is considerable evidence for concluding that the rate of increase in southern Idaho and the adjacent part of Oregon is approximately 1° F. for each 45 feet in depth.[a] In temperate latitudes the increase in the temperature of the earth should be reckoned from a depth of 50 feet below the earth's surface, because the seasonal changes in temperature extend to that depth. At the horizon referred to there is a constant temperature which agrees with the mean annual temperature of the locality chosen. In the portions of Idaho and Oregon under consideration the mean annual temperature is approximately 50° F. In tropical countries the depth to which seasonal changes of temperature extend is less and in arctic regions much greater than that just stated. If, for example, a spring in the region referred to has a temperature of 65° F., or 15° above the temperature

[a] The facts on which this conclusion is based are recorded in Bull. U. S. Geol. Survey No. 199, 1902, pp. 173-174.

of the stratum of no seasonal variation, it would be safe to conclude that the water rises from a depth of at least 675 feet below that stratum or 725 feet below the surface. As the freedom of escape of the waters of springs is usually obstructed, some allowance must be made for its cooling as it rises, so that in the same case just cited 725 feet would indicate the minimum depth to which a drill hole would have to be extended with the hope of penetrating rocks in which water existed under sufficient pressure to cause it to rise to the surface.

In artesian basins there are apt to be localities where there is an escape of the water to the surface, so as to form springs. In such instances the springs usually flow throughout the year without appreciable changes in volume or in temperature, and the water is above the mean annual temperature of the locality where it reaches the surface. Where the structure of the rocks suggests that an artesian basin is present, the occurrence of warm springs within the basin is an assurance that water is present under sufficient pressure to force it to the surface in case wells are drilled. The warm springs referred to may be termed natural artesian wells, and their temperature indicates the depth of the water-charged bed below the surface, and the elevation of the locality where they occur gives a minimum measure of the height of the artesian head.

While warm springs (or those ranging in temperature from about 60° to 100° F.) situated within a region which has the structural features of an artesian basin may be taken as evidence of the presence of a water-charged layer which would supply flowing wells, a hot spring (or one having a temperature of more than 100°) is not so favorable an indication. Hot springs ordinarily rise from such a depth that even if they come from a well-defined water-charged layer it would be impracticable for most purposes for which artesian water is used to reach it by drilling. Although the conditions which lead to the occurrence of hot springs are not well understood, owing to the depth from which their waters rise, there are reasons for believing that they are frequently supplied by fissures that penetrate deep into the earth. The irregularities of fissures are such as to preclude prediction as to where they occur. In the case of every hot spring, however, there is a chance that if a well is drilled near it, even to a moderate depth, a flow of water will be secured, but in such instances the flow of water obtained should be classed as a "developed spring" rather than an artesian well. The fact, however, as previously explained, that water rising from a depth through fissures may charge the pervious beds in an artesian basin renders it evident that both warm and hot springs demand careful study in conducting a search for artesian water.

ROCKS OF THE REGION EXAMINED.

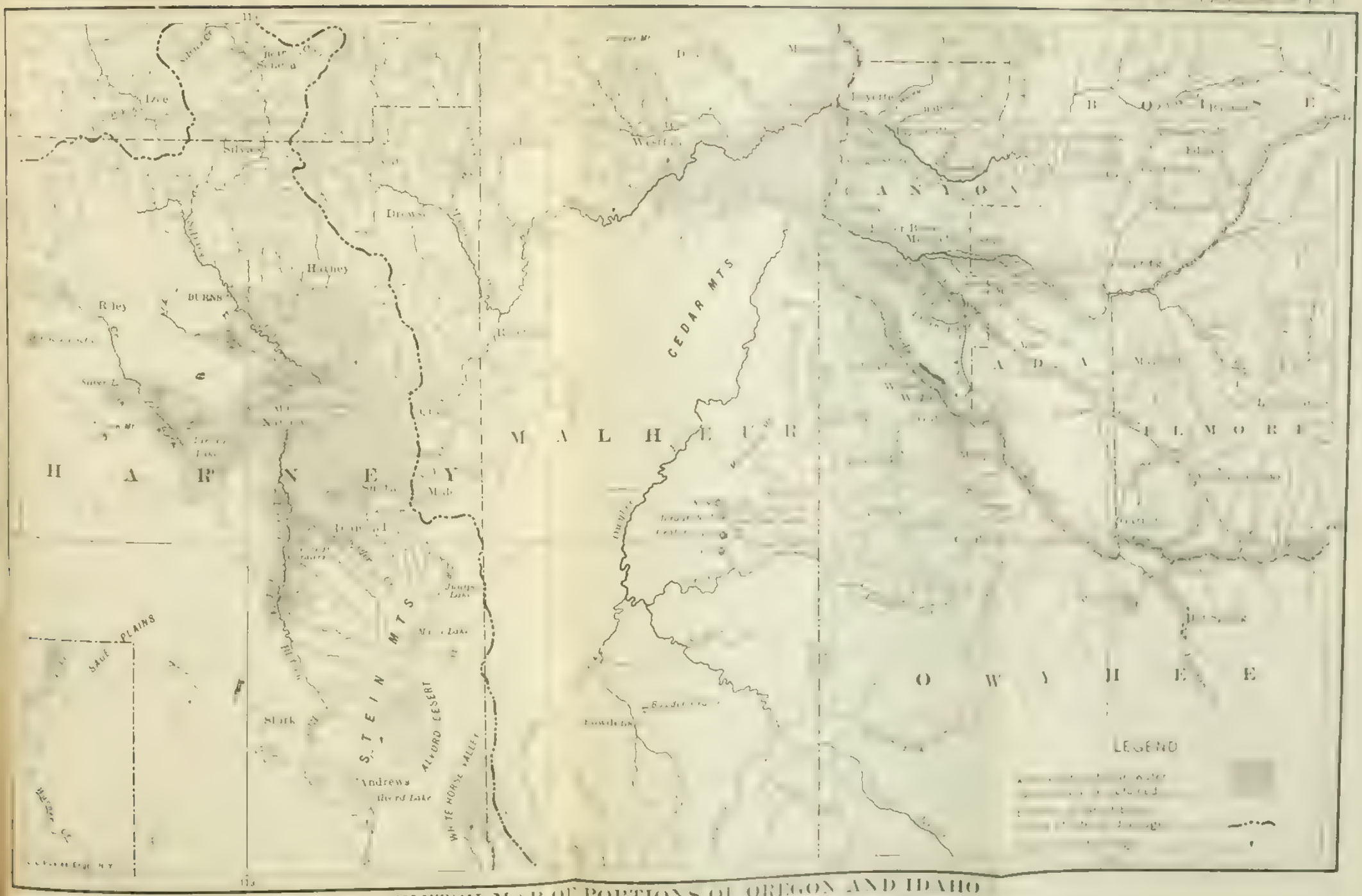
A classification of the most common rocks of southwestern Idaho and southeastern Oregon, sufficiently accurate for the present purpose, is as follows:

- Sedimentary rocks — Conglomerate, sandstone (in part hardened so as to form quartzite), shale, clay, sand, and gravel, together with beds of volanic dust and volcanic gravel or lapilli.
- Igneous rocks
  - Volcanic rocks
    - Lava flows — Basalt. Rhyolite.
    - Fragments blown out of volcanoes. — Basaltic lapilli. Rhyolitic dust and tuff. — Also mentioned above as forming sedimentary beds.
  - Plutonic rocks — The molten material like that extruded from volcanoes at the earth's surface, but which cooled below the surface in fissures, etc.

SEDIMENTARY ROCKS.

The stratified rocks of the region examined, or those composed of fragments of older rocks which have been spread out in layers or strata by the waters of lakes and streams, comprise conglomerate or pudding stone; sandstones; soft, highly calcareous, usually nearly white shales; loose gravel, sand, white volcanic dust; and dark, usually yellowish, volcanic gravel or lapilli. These beds were, for the most part, deposited in lakes during Tertiary time.

Examples of the conglomerate and sandstones referred to may be seen in the hills near where the Owyhee joins Snake River, in the isolated hills near Vale, and in the conspicuous bluffs to the southeast of Malheur and Harney lakes, as well as many other localities. These rocks are usually dark yellow, but occasionally, as near Narrows, are nearly white, and in some instances are sufficiently compact to be used for building stone. Associated with the layers of consolidated pebbles and sand just referred to, and having a wide extent in both Idaho and Oregon, are soft, unconsolidated light-colored shales and marls, and thick beds of nearly white sand and light-colored clay. Beds of this general nature, aggregating more than 1,000 feet in thickness, underlie Snake River Valley between Glenns Ferry and Weiser, and form the conspicuous white bluff along each side of that stream. Similar beds occur also in the lower portion of the valley of Malheur River and beneath the rim rocks of the canyons on the west slope of Stein Mountain. Light colored, and in part greenish shales, outcrop on the west side of Alvord Valley, where they pass beneath the sheets of basalt forming the bold eastern face of Stein Mountain. Fine exposures of rain-sculptured lacustral sediments, usually of a peculiar light-greenish tint, occur on the borders of Owyhee River near the mouth of Jordan Creek. Similar beds are present also in the



SKETCH MAP OF PORTIONS OF OREGON AND IDAHO
SHOWING, APPROXIMATELY, ARTESIAN AREAS

mountains of Owyhee County, Idaho, and are an extension southward of the thick sediments exposed along Snake River. This same formation extends northward from Snake River and is exposed near Boise, and in the valley of Payette River. From its abundant outcrops along the last-named stream, it has been termed the Payette formation by Waldemar Lindgren.[a]

While the Payette formation has a wide extent in Oregon, and possibly reaches to John Day River, where other similar beds outcrop, it is not positive that all the exposures of similar material as far south as Harney and Silver lakes were deposited in the same lake basin. The lacustral sediments beneath the basalt of Stein Mountain have a thickness of fully 1,000 feet, and, as now seems probable, are older than the Payette formation.

Interbedded with the sandstone, shale, etc., of the formations just mentioned, and frequently forming a considerable and at times seemingly the major part of their thickness, are beds of exceedingly fine, white volcanic dust. This dust was blown out of volcanoes during violent eruptions, and falling in lakes, or being washed into them by streams, became interbedded with other sediments or intimately commingled with them. Pure white, stratified volcanic dust, from 10 to 20 feet or more thick, may be seen in the hills on the lower course of Owyhee River, a few miles south of Owyhee. It is also splendidly exposed near Beulah. Outcrops of material of the same nature, conspicuous on account of their whiteness, occur beneath the rim rock near Diamond, in the borders of the small valleys in the northern portion of Owyhee County, Idaho, as well as at a large number of localities in the bluffs bordering Snake River.

An interesting fact in connection with the stratified beds briefly described above is that they contain the bones of animals which are now extinct, but which lived in large numbers in and about the ancient lakes in which the sand, clay, volcanic dust, and other material now exposed and eroded into hills and valleys was deposited. Throughout these same beds, but most abundantly in the thinly laminated white silts and beds of fine volcanic dust, occur fossil leaves, and less commonly the fruits of plants. These plant remains differ from the vegetation living on the earth to-day, and reveal the nature of the luxuriant forests that flourished in the now arid portions of the far West during the Tertiary period of geological history. The fossil bones and impressions of leaves and fruits referred to, and also the shells of fresh-water mollusks frequently associated with them, are of great scientific interest, as they furnish evidence in regard to past climatic changes and the gradual evolution of life on the earth, and enable geologists to determine the age of the beds in which they occur.

[a] Eighteenth Ann. Rept. U. S. Geol. Survey, Pt. III, pp. 632-634; Twentieth Ann. Rept., Pt III, pp. 93-99; Geologic Folio No. 45

The sedimentary beds to which attention has just been directed are in many instances open-textured and of such a nature that water will readily percolate through them, while in other instances they are of the consistency of clay and tend to retain water in the porous beds, if any is present, between them. These conditions indicate that wherever the sedimentary beds have been bent or displaced from their original horizontal position so as to form basins, there is a probability that flowing water may be obtained by drilling wells.

It is reasonable to assume that quartzite or granite is present beneath the Payette formation and associated volcanic rocks, throughout the Snake River Valley. The quartzite is usually a yellowish-white and excessively hard rock, and was orginally a sandstone, but has been altered or metamorphosed, so that the separate grains of quartz sand are no longer distinguishable. The granite is composed principally of conspicuous crystals of quartz, feldspar, and mica, as may be seen in the extensive outcrops in the mountains to the north of Boise, and is of deep-seated igneous origin. When either of these formations is encountered in drilling, the hope of obtaining flowing water by continuing to a greater depth had best be abandoned.

IGNEOUS ROCKS.

VOLCANIC ROCKS.

The rocks which came from volcanoes are by far the most conspicuous of any of the formations in southwest Idaho and the adjacent part of Oregon, and are no doubt of greater extent and thickness than the associated sedimentary beds. They may, with sufficient accuracy, be classified as basalt and rhyolite, but a critical study will no doubt show that what is here termed rhyolite in reality includes several rock species.

Both the basalt and the rhyolite present two conspicuously different phases, due to the manner in which the material composing them was spread out on the earth's surface. These rocks while molten were in part extruded by volcanoes so as to form sheets, which in many instances flowed far and wide over the surface of the land before cooling. In other instances the lava, while yet in the craters from which it came, cooled sufficiently to become rigid and was shattered by steam explosions, and the fragments thus produced were blown into the air and widely distributed through the action of the wind, etc., as sheets of volcanic dust, volcanic gravel, or lapilli and angular fragments, frequently of considerable size. The basalt was spread over the surface of the land, mostly in a molten and even highly fluid condition, and the beds of fragmental material produced were relatively small. The rhyolite, to a great extent, was shattered at the time it was erupted, and the resulting beds of fragments were probably of greater extent and thickness than the sheets of the same material which were

spread out as lava flows. This difference in the behavior of the volcanoes from which the comparatively fusible basalt was erupted and of the volcanoes from which the more refractory rhyolite was discharged is of much significance in reference to the nature of volcanoes, but can not be discussed at this time.

The basalt is a black, compact rock, but is frequently cellular and even scoriaceous on account of the presence in it of steam cavities, and in many localities is columnar. In the region under review it occurs in widely extended sheets, which in general vary in thickness from about 20 to 80 feet. Fine examples occur all along Snake River, but more especially on the northern side of its canyon, in the canyon of Bruneau River, and in the hills and mountains of Malheur and Harney counties, Oreg. The finest exposure of basalt in the region visited by me in 1902, if not the most remarkable in the world, is to be seen in Stein Mountain. The eastern slope of that splendid mountain is composed of the broken and eroded edges of sheets of basalt, which dip westward at an angle of 3° to 4° at the crest of the uplift, but flatten rapidly when traced westward, and present an aggregate thickness of not less than 5,000 feet. Between the sheets of basalt, as observed in at least eighteen instances, there are beds of coarse sandstone, varying in thickness from a few inches to 6 feet. Where the beds of sandstone occur the sheets of basalt are in general about 60 feet thick. From this and other similar evidence the total number of lava flows which occur at the locality referred to is estimated at between 80 and 100.

The widely extended sheets of basalt just referred to, like the sedimentary beds with which they are intimately associated—the sheets of basalt and the beds of sandstone, shale, clay, etc., in many instances alternating one with the other—are of ancient date, and belong principally to the Tertiary division of geological history.

Volcanic eruptions have occurred, however, at intervals from the time the oldest sheets of basalt were poured out in a molten condition down to almost the present day. Recent volcanoes, which discharged great quantities of basaltic lava in the condition both of lava sheets and of angular fragments, occur at three localities in southeastern Oregon. One of these is situated a few miles west of Diamond, Harney County, where there are craters that are built in part of scoria, lapilli, etc., and in part of lava sheets, and are surrounded by extensive lava flows. This group of small volcanoes may with propriety be named the Diamond craters. About 6 miles northeast of the former Bowdens post-office, in Malheur County, and approximately 18 miles south of Owyhee River where Jordan Creek joins it, there is an isolated crater of recent date, built almost entirely of congealed lava, which cooled about the opening in the earth from which it rose. About this Bowden crater, as it may be termed, is a recent lava flow which came from it and spread over at least 150 square miles of coun-

try. The most instructive as well as the latest of the three recent eruptions referred to occurs in the east-central part of Malheur County from 15 to 20 miles west of Jordan Valley, and the hills it built are here named the Jordan craters. The Cow Creek lakes owe their existence to the obstruction to the drainage caused by the extensive sheet of fresh black lava which came from the most northerly and most recent of Jordan craters. The rocks extruded from these recent volcanoes were spread over the surface both as lava flows and as sheets and piles of fragments, and serve in a most instructive manner to illustrate the mode of origin of the more ancient and far more extensive accumulation of similar rock.

The rhyolite, like the basalt, occurs both as massive sheets, which were poured out from volcanoes in a molten condition, and fragmental deposits, which also form well-defined beds. Of the beds originating in these two ways, the sheets of angular fragments, now in many instances firmly cemented and forming a rhyolitic tuff, are far more numerous and more extensive than the associated rhyolitic lava beds. The deposits of white volcanic dust described above as forming a part of the sedimentary formations are composed of the finest of the fragments blown into the air by the volcanoes from which came the material now forming the sheets of rhyolite and of rhyolitic tuff.

The compact, massive rhyolite is lighter colored than basalt, and in Idaho and Oregon is usually purplish on fresh surfaces, but weathers to a rich brown or red It contains conspicuous crystals and grains of quartz, feldspar, and other minerals, and hence usually appears spotted. Frequently the crystals and grains referred to exhibit an arrangement such as would be produced by a flowing motion in the glassy base in which they are embedded.

The rhyolitic tuff is composed of angular fragments of the rock just described, which in most instances are firmly cemented so as to form sheets that are nearly, if not fully, as resistant to atmospheric conditions as the similar material which cooled from fusion without being shattered, as may frequently be seen in the rim rock on the sides of canyons and valleys.

Extensive exposures of rhyolite and of rhyolitic tuff occur in the mountains on the northeast side of Harney Valley, sometimes termed the Crow Creek Mountains. The conspicuous rim rocks on each side of Rattlesnake Creek, near Harney, are of rhyolitic tuff, while certain of the beds, usually cavernous on the weathered outcrops lower down in the walls of the same canyon, are of rhyolite which has a peculiar concentric or spherulitic structure. Again, in the bluffs of Silvies River, to the west of Burns, the edges of a thick sheet of compact tuff are well exposed, and similar rock has a wide distribution in the forest-covered mountains in which Silvies River rises. Other exposures of tuff and of compact rhyolite occur about Silver Lake, at Iron Mountain, and in the Mahogany Mountains. The conspicuous rim

rocks in the vicinity of Diamond are composed of tuff, and similar rock has a wide distribution in the hills near Smith and Mule.

An interesting fact in connection with the sheets of rhyolite and of rhyolitic tuff in southeastern Oregon is that they are younger than most of the basalt of the same region and overlie it. There have been eruptions of basalt, also, since the youngest observed sheet of rhyolite and of rhyolitic tuff was spread out.

The rhyolitic tuff is in many instances highly porous and permits the free percolation of water through it, but in other instances it is firmly cemented and probably nearly impervious. The compact rhyolite is to be classed, in most instances, as an impervious rock, although its weathered outcrops are at times conspicuously cellular. The presence of sheets of these rocks in an artesian basin, together with sheets of basalt and stratified sandstone, shales, clay, sand, etc., would tend to increase the variety among the strata, and in a general way, at least, be favorable to the storage of water under pressure.

PLUTONIC OR DEEP-SEATED IGNEOUS ROCKS.

The molten magmas which rise in volcanoes and in part overflow, so as to form lava sheets, also, in part, cool below the surface in the conduits of volcanoes and in fissures. Many distinctive features in the rocks produced from the same molten magma arise in this way, which it is unnecessary to consider at this time.

Both the basalt and the rhyolite, which occur in extensive sheets in Idaho and Oregon, came to the surface through openings, as fissures, for example, and below the present surface it is to be expected that there were many fissures in which molten rock has cooled, so as to form what are termed dikes. A few dikes were observed in the bold eastern face of Stein Mountain, and indicate that others may be present elsewhere. The dikes referred to are nearly vertical, vary in width 20 to 60 feet, and are horizontally columnar. As is well known, dikes have frequently led to the hardening of the walls of the fissures they occupy and for this and other reasons their presence in an artesian basin might introduce serious difficulties in the way of obtaining flowing wells. If in drilling a well, the locality chosen should chance to be directly above a dike, it is probable that the well would be a failure, even if the usually compact and hard rock of the dike could be penetrated. Where the country rock is concealed beneath deep sheets of soil, alluvial deposits, etc., it is frequently impossible to detect the presence of dikes in the rocks beneath the surface covering, unless they are encountered in drilling or making other excavations. So far as can now be judged, however, the dikes in the artesian basins described in this report are not numerous, and the chances of striking them in drilling are small. A greater danger lies in the fact that they may cut a pervious bed so as to prevent the percolation of water through it.

GEOLOGICAL STRUCTURE.

By geological structure is understood in part the positions occupied by stratified or bedded rocks in the earth's crust. For example, sandstone, shale, etc., originally laid down in horizontal sheets, are now found in many instances to be inclined or folded, and often occupy a vertical position.

The rocks, both sedimentary and volcanic, which underlie southwestern Idaho and southeastern Oregon, were at the time of their formation spread out in nearly horizontal layers, but subsequently they have been depressed in one locality and raised in another, and in certain instances crushed together so as to form great upward and downward folds. In other localities they have been broken along nearly vertical planes, and a portion of the strata on one side of the break has been upraised or depressed in reference to corresponding strata on the opposite side; that is, the beds have been faulted. Examples of gentle tilting of previously horizontal sheets of rocks throughout great areas are furnished in the broad Snake River Plains between Glenns Ferry and Owyhee. To the north of Snake River the rocks are now gently inclined upward to the north, but south of the river the same beds rise when followed southward, and in the Owyhee Mountains the strata are more than a thousand feet above the position they occupy beneath Snake River. This uptilting of stratified beds is well displayed in the hills near the point where Snake River first crosses the Idaho-Oregon boundary. These remnants of formerly much more extensive strata indicate not only the way in which once horizontal beds have been tilted, but bear evidence as to the great amount of denudation that has occurred throughout an extensive region.

Broad and comparatively gentle elevations and depressions of once horizontally stratified rocks occur also in other portions of the region examined; as, for example, in the neighborhood of Harney and Burns. The rocks beneath the extensive valley in which Malheur and Harney lakes are situated slope upward in the hills and mountains about the borders of the basin, as is well shown in the walls of the canyons on the west side of Stein Mountain, in the Crow Creek Mountains, on the border of the canyon of Rattlesnake River, in the hills west of Burns, and several other localities. In general, all about the Harney basin, as it is convenient to term the great depression in which Malheur and Harney lakes are situated, as well as in the country draining to them, the rocks are upraised This basin, however, is not a simple saucer-shaped depression, but has irregularities, and is due to the association of several areas in which upheavals or depressions have occurred.

The broad, gentle undulations in the rocks just referred to, which in some instances have horizontal axes measuring a hundred or more miles, are promising structural features in reference to the hope of obtaining an artesian-water supply.

Of smaller size than the broad and usually somewhat indefinite swells and depressions referred to above are upward folds, or anticlines, and downward folds, or synclines. These are similar in shape and in the manner in which they are produced to the folds or corrugations that may be made by pushing one side of a pile of rugs toward its center; or, on a still smaller scale, by forcing together the sides of a pile of newspapers so as to compress them into folds. In the region under consideration there are several examples of such folds; but, as is commonly the case on all land areas, the relief produced in the manner referred to has been greatly modified by erosion. The upward folds particularly have been cut away, leaving for the most part only their basement portions.

A striking illustration of a great upward bend, involving bedded lava sheets having an aggregate thickness of fully 5,000 feet and a great but unknown thickness of stratified sedimentary deposits as well, is furnished by the north portion of Stein Mountain and the several parallel nearly north-south ridges to the east of it and north of Alvord Desert. The larger features of this rugged belt of country are due to the erosion of a great anticlinal fold, the longer axis of which trends about northeast and southwest. The hard layer of compact basalt in the truncated remnant of the fold now forms the sharp crested ridges to the east of Juniper and Mann lakes, which have a gentle surface slope on one side and a steep escarpment on the other.

A characteristic example of a broad downward fold or syncline may be seen from the summit of Stein Mountain on looking toward the southwest over the region drained by Donner and Blitzen River. The longer axis of this basin trends in a north-south direction and is inclined downward, or pitches, to the north.

Accompanying the bending of rocks so as to form corrugations, breaks sometimes occur, and the edges of the broken layers on the sides of the fracture are upheaved or depressed with reference to each other. In this and yet other ways what are termed "faults" are produced.

When the rocks have been broken and displaced or faulted, the conditions are not favorable for obtaining artesian water. Even if an artesian basin is present, the impervious beds, which would otherwise confine water under pressure, may be broken and permit the water to escape. In this connection it is to be noticed that hot springs are frequently situated on fault lines. In the case of the Stein Mountain fault, a spring with several surface openings having temperatures ranging from 168° to 177° F. occurs on the southwest side of Alvord Desert.

It is principally from the study of the structure of the rocks in any region that the presence of artesian basins is to be determined. The reason why structure may be considered as the controlling condition in this connection is because the other necessary conditions, such as the presence of pervious and impervious layers in a series of stratified

rocks, the presence of water in pervious beds, etc., are of common occurrence; while the requisite conditions for storing water beneath the earth's surface and under pressure are much less frequent, and it is these conditions which are dependent principally on the positions which the rocks occupy—that is, the geological structure. When a saucer-shaped basin is present, the chances are that the other necessary conditions will also exist.

ARTESIAN BASINS.

The four principal areas in southwest Idaho and southeast Oregon in which artesian water has already been discovered, or in which convincing evidence is found that it may be obtained, have already been referred to under the names of the Lewis, Otis, Harney, and Whitehorse artesian basins. Such facts as have been learned concerning each of these basins as are thought to be of immediate value to persons interested in the development of their artesian conditions are here presented.

LEWIS ARTESIAN BASIN.

The portion of this artesian basin in which flowing water may be obtained is situated along Snake River between Glenns Ferry and Weiser, and might with propriety have been named after it, except for the possibility that other artesian basins may be discovered in the extensive region it drains. Lewis, the less frequently used but more appropriate name of the Snake River, has therefore been selected as a convenient term by which to designate the artesian basin under consideration.

The rocks on each side of Snake or Lewis River from near the mouth of Kinghill Creek westward to beyond the Idaho-Oregon boundary are gently inclined or dip toward the canyon of that stream from each side. The inclination of the rocks is most readily seen on the south side of Snake River; as, for example, in the highlands to the east of Bruneau River, and in the hills near the mouth of Owyhee River, where the strata rise when traced southward at the rate of perhaps 100 feet to the mile. This rise, although gentle, is sufficient to carry the strata which underlie Snake River to an elevation of more than a thousand feet above its surface in the hills and mountains of Owyhee County. On the north side of Snake River the rocks are seemingly level, but, as nearly as can be judged, rise gradually to meet the mountains of older rock to the north of Mountain Home, Boise, etc. The inclinations of the rocks just referred to show that they have been bent into a broad trough-shaped depression, the longer axis of which bears about northwest and southeast, and is followed by the canyon of Snake River in a general way from Glenns Ferry to the Idaho-Oregon boundary. In certain localities, however, the axis of the fold is a mile or two north of the river.

On reaching Snake River, in 1901, I observed the general features pertaining to the dip of the rocks just referred to, and at once recognized the possibility of the presence of an artesian basin. Other conditions confirming the truth of this inference, such as the presence of warm and hot springs, were soon discovered, and the fact was learned that several successful artesian wells had already been drilled in Bruneau and Little valleys, thus demonstrating that water under pressure exists below the surface. In 1902 the portion of Snake River Valley lying west of the region traversed the previous year was examined, and the structural basin referred to was found to extend beyond the Idaho-Oregon boundary and to include a wide extent of territory in Oregon.

The eastern end of the Lewis artesian basin is for convenience considered to be near the eastern boundaries of Elmore and Owyhee counties, principally for the reasons that this is the eastern limit in the canyon of Snake River where land suitable for irrigation occurs below the artesian head of the basin as at present known, and also because sufficient study has not as yet been given to the region east of the counties mentioned to justify me in expressing an opinion in reference to the actual eastern extension of the basin in question.

The margin of the Lewis artesian basin can not yet be actually mapped, but within it is included, in a general way, the Snake River Plains in Elmore, Ada, and Canyon counties, and the country in Owyhee County which is drained by northward-flowing streams. In Oregon its boundary is still less definitely known, but it includes the greater part of the northern third of Malheur County. The position of the actual boundary of the basin, or the line from which the rocks begin to slope toward a central axis, is of much less practical moment, however, than the boundary of the country below the artesian head.

As will be stated below, the artesian head of the Lewis artesian basin has not been accurately determined, but provisionally it is taken at 2,500 feet above sea level. This is certainly a safe assumption, as flowing wells now discharge this water at that level, and others, as determined by a less accurate method of measurement, namely, the aneroid barometer, overflow at 2,700 feet above the sea. This indefiniteness is due to the fact that none of the wells in the basin are properly cased, and it was impracticable with the means at my disposal to make definite measurement of the water pressure. However, the area throughout the greater part of the Snake River Canyon or Valley, which is between an elevation of 2,500 and 2,700 feet, is comparatively small, and the extent of territory below the former level is probably more than sufficient to utilize all the artesian water that can be had within its boundary.

The tracing of the territory below the known artesian head in the portion of the Lewis artesian basin which is situated in Idaho is a simple matter, as most of it has been surveyed and accurate contour

maps are available. The maps referred to are published by the United States Geological Survey, and comprise the following sheets of the topographic atlas of the United States: Mountain Home, Bisuka, Boise, Silver City, Nampa, and Weiser.[a] By consulting these maps it will be seen that a large extent of territory adjacent to Snake and Boise rivers lies below the 2,500-foot contour. Practically all of the flat land favorable for agriculture adjacent to Snake River, between Glenns Ferry and the mouth of Boise River, lies below the horizon referred to. That is, the 2,500-foot contour marks, in general, the beginning of the abrupt slopes which rise from the flat lands bordering the river to the margin of the plateau above. In the region referred to, where the surface is less than 2,500 feet above the sea, wells put down to the requisite depth, which will be discussed later, should yield flowing water. A considerable extent of country about Nampa and Caldwell, much of the valley of Boise River, and of the Snake River Valley between the mouths of the Boise and Weiser, are also below the 2,500-foot contour, and so far as can now be judged, wells put down in this region should also yield an artesian flow.

There are no good maps of the region in Oregon embraced within the Lewis artesian basin, and it is impracticable to state at present where the plane of the assumed artesian head, 2,500 feet above the sea, intersects the surface. Much of the nearly level land that is otherwise favorable for agriculture adjacent to the west side of Snake River from where it first crosses the Idaho-Oregon boundary northward to the vicinity of Weiser, and an extensive tract in the lower 25 miles of the valley of Malheur River are certainly within the limit referred to, and careful tests of the artesian conditions should be made. A rough estimate of the extent of agricultural land in Idaho and Oregon that is within the Lewis artesian basin and below its known artesian head shows it to be not less than 1,000 square miles.

As the conclusions just presented will no doubt be considered too sanguine by many persons, I desire to indicate briefly the evidence, other than the geological structure, on which they are based, and at the same time to furnish data which will assist in the more complete development of the artesian conditions.

SPRINGS.

Within the Lewis artesian basin there are a number of warm and hot springs, which show that water under pressure exists below the surface.

Mountain Home.—About 3 miles east of Rattlesnake Creek, at the locality where "Old" Mountain Home was located, there is a fine spring, or group of springs, with a maximum temperature of 167° F.

[a] These maps, on a scale of about 2 miles to 1 inch, with a contour interval of 100 feet, each sheet including about 850 square miles, can be purchased of the United States Geological Survey for 5 cents each.

The surface level is about 3,550 feet. The water is of good quality, but is not now utilized except in a small way for bathing. No attempt has been made to develop the spring by boring, although good land occurs near at hand on which any water that might be obtained could be used for irrigating.

Boise.—Springs issue from sandstone of the Payette formation, 4½ miles east of Boise, at an elevation of about 2,750 feet. The water has a faint smell of sulphureted hydrogen, contains a small amount of mineral matter in solution, and varies in temperature from 125° F. to near the boiling point.

Salmon River.—A small spring on the left bank of Snake River, about 4 miles above the mouth of Salmon River, Cassia County, has a temperature of 131° F. Another hot spring occurs in the canyon of Salmon River, about 5 miles above its mouth.

Little Valley.—Near the head of Little Valley, Owyhee County, there are several warm springs and one small hot spring, temperature 101° F., which is now partially developed by drilling wells near it to a depth of 40 feet.

Bruneau Valley.—Near Hot Spring post-office there are several copious springs, with a temperature of 109° F. One of these has been developed by drilling a well near it to a depth of 240 feet. The well furnishes 7 gallons of water per minute.[a]

Walters Butte.—A copious spring about 1 mile west of Walters Butte, Canyon County, where the elevation is 2,340 feet, has a temperature of 67° F. This spring is very likely due to the leakage from water-bearing strata, and suggests that wells put down in its vicinity to a depth of about 350 or 400 feet would yield a surface flow of water. Near Walters Butte there is an area of about 4 square miles of favorable land that lies below the known artesian head of the basin in which it is situated.

Enterprise.—On the south side of Snake River, at Enterprise, Owyhee County, there is a spring issuing at an elevation of 2,220 feet, with a temperature of 128° F., which discharges approximately 7 cubic feet of water per second and is now utilized for bathing and for irrigating about 10 acres of land. The water rises where there is a thickness of nearly 1,000 feet of soft lake sediment (Payette formation) and, as its temperature indicates, comes from a depth of approximately 4,500 feet.

Sands.—From 2 to 3 miles west of Sands, in Owyhee County, and near the point where Poison Creek descends through a deep cleft in the upland and enters Snake River Valley, there are copious springs, with a temperature of about 100° F., which are used for irrigation. These springs rise where the surface level is approximately 2,450 feet, and may reasonably be supposed to be supplied by the leakage of porous

[a] Concerning the five localities mentioned above additional information is presented in Bull. U. S. Geol. Survey No. 199.

beds in the Payette formation. They occur within the Lewis artesian basin, nearly up to the known artesian head of that basin, and are a favorable indication that wells drilled in their vicinity to a depth of approximately 1,000 feet would prove successful, but from other evidence it is to be presumed that flowing water might be expected on drilling to a less depth. To the north of the conspicuous line of bluffs trending northwest and southeast and passing Sands on the south is a large tract of good land, embracing in fact something like 100 square miles, which is below the level of the springs just referred to, and where one is justified in assuming that artesian water can be had.

Owyhee Canyon.—In the canyon of the Owyhee, about 6 miles south of Owyhee post-office, there is a copious hot spring, which issues from openings in volcanic rock and has a temperature of about 115° F. But little irrigable land occurs near this spring, and for this reason an attempt to develop it and concentrate its flow would at present not be warranted.

Vale.—At Vale, on the east border of Malheur River, there is a spring with a temperature of 198½° F. Near at hand a well put down to a depth of 140 feet yields a strong flow of water with the same temperature. These springs are in a broad region underlain by the Payette formation, but it is presumed, are supplied by fissures. These springs rise at the west base of a prominent hill, composed in part of cemented gravel, and the manner in which they are depositing mineral matter suggests that the pebbles and sand in the hill were cemented by the same process. Other similar hills or buttes are situated a mile or two northward, and another is a conspicuous object about 5 miles farther north. Each of these exceptional features in the topography of the valley is due to the resistance offered to erosion by the hard beds they contain, and suggest that in each case hot springs rising through the Payette formation have led to a local hardening of its more porous strata and, in consequence, their preservation as erosion progressed. This suggestion was not tested by examining each of the hills referred to, but may be of interest to students of geology who visit them in the future, and in addition may be found to explain the manner in which hot springs sometimes occur in artesian basins, but do not appear to have any connection with neighboring artesian wells.

Westfall.—On the stage road between Vale and Westfall, in sec. 9, T. 18 S., R. 43 E., there is a spring with a temperature of 168° F. at an elevation by aneroid barometer of 2,400 feet. This discharges by estimate about 2 miners' (California) inches, or 100 cubic inches per second, but the total flow from the several small openings is probably greater than this. The waters have a slight odor of sulphureted hydrogen, and are depositing lime in the form of cellular calcareous tufa. The water is used for bathing, and in part is conducted to a house

through a pipe and used for cooking, etc. A small spring near at hand, supplied by percolation from the alluvial material in the bed of Bully Creek, has a temperature of 54° F.

The hot spring just mentioned is within the territory included in the Lewis artesian basin, and, judging from the approximate measures available, is below the artesian head of that basin, but owing to the high temperature of its waters and the consequent depth from which they rise, and the nature of the rocks in the vicinity, little if any significance in reference to the probability of obtaining artesian water in its neighborhood can be attached to it.

Beulah.—Small springs in the valley of Warm Creek, near Beulah, have a temperature of 185° F.

DRILLED WELLS.

In the portion of the Lewis artesian basin examined by me in 1901 it was found that several moderately deep borings had already been put down, several of which yielded a surface flow of water. Some account of the borings referred to was presented in my report for the year named,[a] but for the purpose of bringing together all the available evidence furnished by borings concerning water pressure, etc., within the Lewis artesian basin a brief account of those previously described is here inserted.

Boise.—To the north and east of Boise and within 2 miles of the city several flowing wells have been obtained by drilling in the Payette formation, and the water they supply is now utilized for city purposes. Boise is fortunate in possessing both cold and hot artesian wells. The following facts concerning them are compiled from a report on the geology of the Boise region of Waldemar Lindgren.[b]

The several cold artesian wells at Boise (temperature about 55° F.) are situated in the gulches north of the city and at an elevation of about 2,750 feet. They vary in depth from 400 to 609 feet, but since this information was obtained some of them have been deepened. The materials passed through in Hulls Gulch are sand and sandstone, 200 feet, and clayey beds, 200 feet, below which water was obtained. In the deepest well there are below the clay 40 feet of sand, 20 feet of clay, and 46 feet of solid basalt, below which clay occurs again. These wells yield from 40 to 250 gallons per minute, and their combined flow is stated to be about 670 gallons per minute. The water is stored in a covered reservoir and from there conducted into the city water mains.

Two wells drilled on the Davis ranch, in the next gulch north of Hulls Gulch, to a depth of 150 feet yield 40 gallons of water per

[a] Bull. U. S. Geol. Survey No. 199.

[b] Geologic Atlas U. S., folio 45, Boise, Idaho; published by the U. S. Geol. Survey and sold for 25 cents per copy.

minute. A well drilled to a depth of 400 feet in a ravine south of Hulls Gulch passed through clay and failed to reach water under pressure.

The hot artesian wells at Boise are situated two miles southeast of the city. Three of these, the water of which is piped to the city and extensively used for heating, baths, etc., have depths of 394, 404, and 455 feet. The character of the rocks penetrated is not definitely recorded, but it is stated that the drill, after passing through sandstone, penetrated several sheets of basalt, below which occurred red volcanic tuff or fragmental volcanic rock more or less thoroughly cemented and containing much black sand. The combined discharge of the three wells is 550 gallons a minute. The water is slightly charged with mineral matter in solution (about 300 parts in 1,000,000) and has a temperature of 170° F. The surface elevation is nearly 2,800 feet, and the water is under sufficient pressure to cause it to rise in a tube open at the top about 50 feet above the surface, or to an elevation of 2,850 feet above the sea. Several wells have been drilled on the United States military reservation a mile east of Boise, at least two of which discharge warm water. Their depths are 450 and 482 feet. The surface elevation is 2,850 feet. From the first mentioned a small flow of water with a temperature of from 75° to 140° F., increasing with depth, was obtained. The second gave a flow of about 35 gallons per minute, the water having a temperature of 90° F. These wells are located near a small tepid spring, and penetrated first 130 to 160 feet of sandstone, then 72 to 116 feet of hard, black lava (basalt), below which occurs a series 200 to 250 feet thick of clays and red basaltic tuff rich in magnetite (black sand) and sometimes containing also iron pyrites.

Other artesian wells in the neighborhood of Boise are briefly described in the Boise folio referred to above.

Both the cold and the hot artesian wells near Boise are in the Payette formation and associated and interbedded sheets of basalt which underlie the Snake River Plains. These same beds outcrop on the border of Snake River Canyon, and south of Snake River rise to an elevation of 4,000 feet or more in the Owyhee Mountains. These facts, together with the geographical position of the wells and the elevation at which they are located—that is, about 2,850 feet—render it at least possible that they belong to the Lewis artesian basin.

Bruneau Valley.—In the upper portion of Bruneau Valley there are three flowing wells, each 2½ inches in diameter, which, together with the numerous hot springs of the same region briefly described above, show that an abundance of water exists at a moderate depth and under sufficient pressure to cause it to rise to the surface if openings are provided.

On W. N. Roberson's ranch, about 2 miles north of Hot Spring

post-office and on the west side of the valley, a drilled well having a depth of 240 feet delivers about 7 gallons of water per minute, having a temperature of 109° F. This well is within a few feet of a large hot spring having the same temperature, the flow of which was not diminished when the well was drilled. The elevation of the surface at this point, by aneroid, is 2,750 feet. The section passed through, as reported from memory by Mr. Roberson, is as follows:

Section at Roberson's ranch.

	Feet.	Inches.
Light-colored sandy clay (Payette formation)	236	
Granular black layer, like basalt (volcanic lapilli)		10
Blue clay (Payette formation)	4	
Black lava	Several inches.	
Total depth, approximately	240	

The water is used for household purposes and for irrigation.

Nearly opposite the well just described, on the east side of the valley and at an elevation approximately 50 feet higher, a well drilled to a depth of 230 feet, on land belonging to Mr. A. H. Pence, gave a small surface flow.

On B. Whitson's ranch, on the eastern side of the valley, about 3 miles north of the two wells just mentioned, where the surface elevation is by aneroid 2,750 feet, a well 700 feet deep discharges about one-third cubic foot of water per second. The temperature is reported to be 90° F.

These three wells derive their water from different depths, and seem to indicate that water under pressure exists in at least three disconnected pervious layers, or else that a source of supply more deeply seated than has been reached by any of the drill holes yet made charges porous beds above it through fissures. The abundance of hot springs in the same vicinity apparently favors the latter hypothesis.

Little Valley.—Near the head of Little Valley, 9 miles west of Bruneau, there are five flowing wells, which range in depth from 150 to 215 feet, each drilled with a 2½-inch bit and poorly cased. The water is of good quality and has a temperature of about 67° F. The flow varies somewhat with seasonal changes, being greatest in winter and spring and least in summer and fall. In most of these wells the pipes have become clogged and the discharge is small. One of the stronger of the wells delivers in August a gallon of water in seven minutes, and is said to discharge about a gallon per minute in winter. Neighboring springs have various temperatures, ranging from 56° to 59° F.

These shallow wells, some of which began to flow when a depth of 60 to 70 feet was reached, are in a broad, deeply filled alluvial valley and evidently depend for their water supply on an alternation of pervious and impervious beds in the alluvial deposits. The source of the water for the several cold springs is no doubt the creeks which

flow from the mountains to the south, but the wells must be supplied from a deeper source.

Little Valley is situated within the Lewis artesian basin and is lower than the flowing wells near Hot Spring post-office, in Bruneau Valley, but the wells referred to above do not furnish a test of what may be termed the true artesian condition. Near the wells just described, but nearer the head of Little Valley, there is a small hot spring which rises through soft, white lake beds, and which has a temperature of 101° F. Five drill holes, put down to a depth of 40 feet in the immediate vicinity of this spring, resulted in a marked increase in the outflow. The discharge is now about one-half cubic foot per second. The wells are not cased, and there is reason to believe that larger holes, with proper casing, would lead to a greater discharge.

Guffey.—In the small valley cut by Dry Creek, about 1½ miles southwest of Guffey, Owyhee County, a well drilled to a depth of 568 feet, but not completed when examined (July 12, 1902), passes through 30 feet of loose surface gravel and then about 538 feet of soft light-covered strata belonging to the Payette formation, containing three seams of hard material, and reached a hard rock, perhaps quartzite, which checked the drill. The well is 3 inches in diameter. A surface flow was obtained from a depth of 160 feet, and an additional flow at 416 feet. The discharge is nearly 1 cubic foot of water per minute; temperature 76½° F. The well is not cased below a depth of 38 feet. Elevation at surface 2,375 feet, or about 160 feet above the adjacent portion of Snake River.

In a small gulch at Guffey and about 120 feet above Snake River, a well bored with a 1½-in[illegible] hand auger to a depth of 30 feet through light-colored beds, probably shale of the Payette formation, at first discharged about 1 gallon of water per minute, but has since ceased to flow.

Central.—Near Central (Barnard Ferry), in the Snake River Canyon, and from 7 to 9 miles northwest of Guffey, four artesian wells have been drilled. All of them are situated near the bottom of the valley, and within a distance of 1½ miles of Central, toward the southeast, where the elevation is approximately 2,300 feet. The records of these wells are as follows:

On the land of Alfred Cox a 3-inch well completed in June, 1902, has a depth of about 1,033 feet. It is cased from surface to a depth of 39 feet and discharges by estimate one-half gallon of water per second; temperature 100° F. Flowing water was first reached at a depth of 600 feet, and the delivery at the surface steadily increased as long as drilling was continued. The water brings sand and gravel to the surface with it. The contract price of the well was 25 cents per foot, the owner furnishing wood and water for the engine used in drilling. The casing used was also provided by the owner of the land and cost about 50 cents per foot.

About one-half mile west of the Cox well a boring approximately 1,000 deep was put down in 1901, which failed to reach water under sufficient pressure to force it to the surface. No other record in reference to this boring has been obtained.

On the farm of P. B. Smith, adjacent to the land of Mr. Cox, and about 1¼ miles southeast of Central, an artesian well drilled in 1901 has a depth of 940 feet, is 3 inches in diameter, is cased to a depth of 30 feet, and discharges about one-third of a gallon of water per second; temperature 98° F. Water which rose to the surface was first reached at a depth of 550 feet. At 700 feet a seam of black sand, etc., was penetrated and the flow of water increased. At the bottom of the well the drill dropped about 3 feet, having reached a stratum of sand and gravel, from which the main supply of water is derived. The well discharges sand and gravel. Cost about 25 cents per foot.

On the land of Mr. Barnard, about one-half mile southeast of Central, a well drilled in 1901 has a depth of about 1,035 feet, is 3 inches in diameter, cased for a short distance at the top, and discharges, by estimate, 1 gallon of water per second, with a temperature of 106° F. At Mr. Barnard's home, in Central, a well drilled in 1901 to a depth of 720 feet, delivers about three-fourths of a gallon of water per second, not measured, with a temperature of 99 or 100° F.

The four wells near Central just referred to were all drilled in the unconsolidated lacustral deposits, mostly sandy clays and soft shales of the Payette formation. A notable fact in connection with them is that no sheets of basalt were encountered. The water from each of the wells is used for irrigation.

Enterprise.—About 3½ miles down Snake River from Central or Barnard Ferry is the post-office known as Enterprise, situated near Warm Spring Ferry. Within a radius of about 1¼ miles of Enterprise and to the southeast there are 4 artesian wells.

At the home of George Newell there are 2 flowing wells, one with a depth of 340 feet, cased with 2½-inch pipe, temperature of 87° F., and the other 385 feet deep, 6 inches in diameter; temperature 90° F. The surface elevation is about 2,300 feet. The flow of water from the larger well, particularly, is strong, but on account of leakage about the pipe could not be measured. An estimate places the combined flow from the two wells at about 1 gallon per second. The water is used for irrigation. About 1½ miles southwest of Mr. Newell's home, where the elevation is 2,500 feet, a well drilled in 1901 to a depth of 165 feet, diameter 10 inches, discharges, by estimate, about 2 gallons of water per second; temperature 87° F. The water is used for irrigation. This well was begun in igneous rock, probably rhyolite, but at a depth of a few feet entered clay, and below the clay several changes in the nature of the material occurred, but an accurate record has not been preserved. Near where the well was drilled

there is a small spring of warm water. Approximately one-half mile west of Mr. Newell's ranch, on land reported to belong to Mr. Shirley, a well was drilled in 1891 to a depth of about 580 feet.

The four wells just referred to, with the exception of the 10-inch well, were drilled in the light-colored sedimentary beds of the Payette formation and, like those near Central, have surprisingly high temperatures for their depth. They are within a distance of 1½ miles of the copious hot spring at Enterprise, which has a temperature of 128° F., and, as it seems justifiable to assume, derive a part of their water at least from that or some other similar source.

Ontario.—The records of two drill holes made at Ontario, Oreg., are as follows:

A well owned by the city of Ontario, incomplete in October, 1902, has, as I am informed by Mr. A. L. Sproul, of Ontario, a depth of 1,025 feet, is 4 inches in diameter, and reached water at 195 feet, which rose to within 6 feet of the surface. The material passed through is sand and gravel to a depth of 35 feet and the remainder blue clay. The water is charged with gas, which, when properly confined, burns constantly. Cost of the well, $750.

The well just described is situated where the surface elevation is between 2,100 and 2,200 feet, or well below the artesian head of the Lewis artesian basin. The well is not cased, and the rise of the water to within 6 feet of the surface makes it probable that if proper tests of the water pressure should be made it would be found that a surface flow could be had by putting in proper casing.

The second well at Ontario, owned by A. F. Boyer, completed September, 1902, 3 inches in diameter, has a depth of 215 feet; water rose and overflowed. Gas is discharged with the water. Material passed through: Soil, 10 feet; gravel, 20 feet, and the balance shale. Cost, $100.

Vale.—A flowing well at Vale, Oreg., drilled near a hot spring to a depth of 140 feet, as already stated, discharges a strong flow of water so long as the casing is not obstructed by mineral matter deposited from it, and has a temperature of 198½° F. This well may be considered as a developed hot spring and has but little significance in reference to the artesian water supply of the basin in which it is located.

Summary.—The artesian wells near Guffey, Central, and Enterprise collectively present certain interesting facts. They are located essentially on a line extending northwest and southeast and measuring about 11½ miles. At the west end of the line is the hot spring at Enterprise. The depth of the wells and their temperatures are as follows, beginning at Guffey and approaching Enterprise:

Depth and temperature of wells at Guffey, Central, and Enterprise.

Locality.	Distance from Enterprise hot spring.	Depth.	Temperature.	Temperature gradient.
	Miles.	*Feet.*	*Degrees F.*	
Guffey	11¼	538	76½	18.42
Central	5	1,033	100	19.66
Do	4¾	940	98	18.54
Do	3¾	1,035	106	17.57
Do	3½	720	100	13.40
Enterprise	1	340	87	7.83
Do	1	385	90	8.37
Do	1¼	165	87	3.10
Enterprise hot spring			128	

The temperature gradient, it will be remembered, is obtained by dividing the depth of a well below the stratum of no seasonal variation in temperature, assumed as 50 feet, by the number of degrees the temperature of the water discharged exceeds the temperature of the stratum of no seasonal variation, assumed to be 50° F. The temperature gradient, then, shows the depth in feet for each increase of 1 degree in temperature.

As is indicated in the above table, the temperature gradient in the region considered increases in a conspicuous manner as the distance from the Enterprise hot spring decreases. An exceptional increase, however, is seen in the case of the last well mentioned in the table, which, as noted above, is near a small tepid spring, and no doubt for this reason shows a more rapid increase of temperature with depth than any of the others. Not considering the well just referred to, the temperature gradient increases as the Enterprise hot spring is approached, but the rate of increase can not be accurately determined from the data available, since the wells are not cased and are not supplied from the same stratum.

The facts just presented seem to indicate that the porous beds in the Payette formation in the vicinity of Enterprise are supplied in part at least from the hot spring at that place. A legitimate conclusion seems to be that the rocks beneath the Payette formation are fissured and that hot water rising through the fissure has charged the porous beds above. Whether there is a deep artesian basin beneath the Payette formation or not there are no data for judging. In general, however, hot springs rise through deep fissures and are probably in most cases not an indication of the presence of a true artesian basin. As has already been stated, the Lewis artesian basin was formed by a bending of the rocks after the Payette beds were laid

down, and this bending no doubt affected a great thickness of the earth's crust below the beds now forming the surface. For this reason it is possible that a true artesian basin exists, the porous beds of which are depressed in the vicinity of Snake River to a depth of 4,000 or 5,000 feet.

In addition to the supply of water reaching the Payette beds from below, the shape of the basin and the fact that the beds composing it outcrop in the hills and mountains bordering the Snake River Plains on the north and south make it evident that additional water may reach the central part of the basin by descending from the surface.

The most logical conclusion to be drawn from all the evidence presented in reference to the probability of obtaining water in the Lewis artesian basin seems to be that flowing water may be expected when a well is so drilled as to penetrate deeply or pass through the Payette formation at any locality within its borders where the surface elevation is less than 2,500 feet. As already stated, 2,500 feet is the minimum measure of the artesian head, as shown by existing wells, but the true artesian head may considerably exceed this amount.

The wells in Bruneau Valley, as shown by an unsatisfactory method, namely, aneroid barometer measurements, have an altitude of 2,700 feet; and the artesian head at Boise is about 2,850 feet. It is not safe at present, however, to accept any measurement of the artesian head in excess of 2,500 feet, and until more wells are drilled all attempts to obtain flowing water should be confined to localities below that horizon. It chances that nearly all the good land along Snake River and in the lower portions of Malheur Valley and much of that in Boise Valley are below 2,500 feet. Abundant localities for developing the Lewis artesian basin are thus available and should be tested before attempts are made to obtain artesian wells on the uplands.

The wells drilled in Snake River Valley at Central, Enterprise, Ontario, and other places passed through soft strata and did not show the presence of beds of basalt or other hard rock in the Payette formation. It is probable that only soft beds will be encountered in drilling to a depth of about 1,000 or 1,200 feet in the portion of Snake River Valley between Guffey and Weiser, but no positive assurance that such will be found to be the case can at present be given.

As may be judged from the facts above presented in reference to the occurrence of hot springs near the artesian well now flowing, the most favorable localities for drilling additional wells may be assumed to be near where warm or hot springs rise through the Payette formation. A qualification of this statement is suggested, however, by the fact that the hot spring at Vale is depositing mineral matter in the beds it passes through in rising toward the surface, and presumably in this way forms for itself a conduit which prevents its water from spreading laterally. This exceptional condition is also indicated by

the exceptionally high temperature of the spring referred to. In choosing a location for a well, therefore, it would be best, at least until more facts are gathered in this connection, to avoid the proximity of a hot spring that is depositing calcareous silica, tufa, gypsum, etc. The most favorable locality, so far as I can now judge, for continuing the development of the Lewis artesian basin is in the extensive flat in the Snake River Valley to the north of Sands.

EASTWARD EXTENSION.

On a preceding page it was stated that the Lewis artesian basin begins on the east near the mouth of Kinghill Creek, that limit being chosen mainly for the reason that but little land suitable for irrigation exists in the canyon of Snake River above the locality mentioned. The upraised rim of the basin extends farther east, however, but what its limits are is as yet unknown.

In my report on the geology and water resources of the Snake River Plains[a] some facts concerning artesian wells in and about the Rock Creek Hills were presented. It now seems not improbable that these wells are in reality situated in the Lewis artesian basin, and it may perhaps be shown by future investigations that the wonderful springs in Snake River Canyon, between Bliss on the west and the neighborhood of the mouth of Salmon River on the east, may be due to the escape of artesian water from the same basin. While there are no newly acquired facts to report concerning the region just referred to, lying south of Shoshone Falls, the study of the Lewis artesian basin certainly indicates that the probability of success in case wells are drilled there is greater than seemed evident when the report on the explorations was made by me in 1901.

OTIS ARTESIAN BASIN.

Otis Valley is situated on a creek of the same name in the extreme northeast portion of Harney County, Oreg., about 6 miles northeast of Drewsey. The valley has a flat bottom, measuring by estimate 5 by 6 miles in diameter, and contains a considerable amount of good land. About 1,900 acres are now under irrigation. The valley is underlain by sedimentary beds consisting largely of white volcanic dust, presumably belonging to the Payette formation. The bordering uplands are composed in part and perhaps principally of basalt, but the sedimentary beds and layers of volcanic dust which occur beneath the valley have also been bent upward in its elevated rim. The dip of the beds about the east side of the valley is west or toward its center at a low angle, and on the south side, as is revealed in the hills at Drewsey, the dip is northward. My examination was not so complete as I desired, but I think was sufficient to show that the valley is a structural basin, on the west side of which there is perhaps a break

[a] Bull. U. S. Geol. Survey No. 199, 1902.

or fault. The structure is such as to suggest the presence of an artesian basin, and in addition copious warm springs on its eastern side show that water under pressure exists below the surface. To term the region in which Otis Valley is located an artesian basin, however, will be justified only when the presence of water under sufficient pressure to force it to the surface is demonstrated, but the conditions observed seem to warrant a careful test by drilling. The pioneer well should be put down on the east side of the valley, a short distance to the west of the warm springs referred to. The area of the land below the level of the artesian head suggested by the elevation at which the warm springs come to the surface is about 10 or 15 square miles.

HARNEY ARTESIAN BASIN.

The region embraced within what is here termed the Harney artesian basin is so great that I could not in the time available examine it with the care it deserves, but I crossed it and visited various commanding summits so as to see more or less thoroughly its entire extent. The area embraced in the outer rim of the basin includes in a general way the region drained by streams which during the rainy season flow to Malheur and Harney lakes, and includes perhaps two-thirds of Harney County, Oreg. The principal streams referred to are Silvies River, which flows southward past Burns and enters Malheur Lake from the north, and Donner and Blitzen River, which rises on Stein Mountain, flows northward, and also enters Malheur Lake. The distance between the sources of these two streams is about 135 miles in a straight line. The breadth of the outer rim of the basin in an eastwest diameter is somewhat indefinite, but measures approximately 50 miles.

The outer rim of the Harney artesian basin is sharply limited on the southeast from near Andrews northeast to beyond Juniper Lake, a distance of 50 or 60 miles, by the east base of Stein Mountain. Its eastern border is in the Crow Creek Hills, and from these it passes northward and curves about the head branches of Silvies River, and then, bending southward, passes to the west of Silver Lake, Iron Mountain, and south of Harney Lake to the source of Donner and Blitzen River. The border is well defined, except in the broad region, with comparatively mild relief to the southwest of Silver and Harney lakes, where the strata are in general nearly flat. The basin is not a single saucer-shaped depression, but consists of at least two troughs or synclines, one in the region drained by Silvies River and the other on the west side of Stein Mountain and drained by Donner and Blitzen River. There are, besides, other folds and irregularities which it is not necessary to describe at this time.

The statements just given indicate that the Harney artesian basin has a structure such as is favorable for the accumulation of water in any porous beds which may be present, but before it is decisively pronounced an artesian basin other evidence should be obtained.

SPRINGS.

There are several warm and hot springs in the broad, generally flat region about Malheur and Harney lakes, but only a few of these were visited by the writer.

Burns.—On the border of Harney Valley, beginning about 3 miles southwest of Burns, a number of springs come to the surface at the base of a cliff of basaltic agglomerate. These have a temperature of from 75° to 80° F. The surface elevation is about 4,100 feet by aneroid, or the same as the general level of the broad, flat lands flooring the valley to the south of Harney and Burns. These springs are of considerable volume, and, as I have been informed, flow throughout the year without sensible variations either in volume or temperature. The water is drunk by stock, but is not used for irrigation except so far as the raising of wild hay is concerned.

Little Sage Hen Valley.—A number of springs come to the surface in the flat, alluvial lands forming the bottom of Little Sage Hen Valley, and, spreading over the land, serve to irrigate extensive natural meadows. Their temperature is in general 63° to 64° F.

Silver Lake.—On the west side of Silver Lake, and along Silver Creek, between it and Harney Lake, there are several warm and hot springs,, flowing only during the rainy season, the waters of which serve to naturally irrigate the adjacent lands. The valley of Silver Creek is a broad, flat, swampy meadow, on which great quantities of wild hay are cut every year.

Harney Lake.—To the southeast of Harney Lake and about one-half mile from its shore, there is a spring of clear, tasteless water, with a temperature of from 145° to 150° F. The volume is by estimate about 6 gallons per second. An attempt to utilize the water for irrigation has been abandoned. The spring is situated near the south base of a bold hill, composed mainly of sandstone, and rises through soft, usually white, lacustral sediments resembling the Payette formation.

Malheur Lake.—In the bed of Malheur Lake, near its southern end, and exposed in summer when the lake is low, there are small springs with a temperature of 64° F. Copious hot springs occur near the eastern end of the lake and at a distance of 4 or 5 miles from the bold bordering uplands of the valley, but these were not visited by me.

Summary.—All of the springs enumerated above present the usual characteristics of warm and hot springs, and furnish evidence that water under pressure exists below the surface. They are widely separated, and in all instances except, perhaps, at the locality near Burns, rise through the soft beds which floor the Harney basin. Their high temperature in several instances indicates that the water rises from a considerable depth, but not from a depth greater than that to which the beds in the basal portion of the basin are depressed. In this connection I may state that the lacustral sediments exposed

beneath 4,500 feet of basalt on the west side of Stein Mountain dip westward at an angle of 3° or 4°, their inclination gradually decreasing, however, with distance from the outcrop, and it is reasonable to assume that they pass under Harney Valley at a depth of certainly 6,000, and probably of 10,000 or more feet. Similar evidence of the great thickness of the strata which are deformed so as to make the Harney artesian basin is furnished in the portion of its upraised rim that forms the mountains to the west of Harney and Burns. Porous beds at any such depth as that just considered, however, are, for practical purposes, beyond the reach of the drill; but as the heated water, in several instances, rises to the surface through the strata forming the upper portion of the great series of rocks involved in the deformation of the basin, and through sedimentary deposits of later date now forming the floor of Harney Valley, there are reasons for believing that the porous beds near the surface have been charged in part with water from below and furnish artesian conditions.

DRILLED WELLS.

In addition to the testimony furnished by the geological structure and by springs, certain borings made near Harney and Burns favor the hope that flowing water can be had at a moderate depth in Harney Valley.

Harney.—About 5 miles east of Harney, on land belonging to Fred Haines, sec. 2, T. 23 S., R. 32½ E., a well 3 inches in diameter, drilled in 1896 to a depth of 507 feet, struck water at a depth of between 200 and 300 feet, which rose to the surface. The well is not cased, and the water now stands 6 feet below the surface and has a temperature of 49° F. The material passed through was soft to a depth of 100 feet, and below that depth consisted of black lava, clay, etc., but no definite record is available. This well at first yielded a true artesian flow, but, as nearly as can be judged, has caved in, owing to lack of casing, and the water supply at present is from percolation through porous beds near the surface. The temperature of the water now being pumped indicates that it comes from about 50 feet below the surface and has its ultimate source in the neighboring hills. The cost of drilling the well was $1 per foot.

Burns.—A well drilled at the expense of Harney County in 1893, at a locality about 6 miles southeast of Burns, in sec. 13, T. 23 S., R. 31 E., was continued to a depth of 848 feet. The well at the top has a diameter of 6 inches, but narrows near the bottom to 4 inches. At the depth of 350 feet water was reached which rose and overflowed at the surface, but after an attempt to improve the well, made in the spring of 1902, it ceased to flow. The water in August, 1902, stood 3 feet below the surface and had a temperature of 49° F. The first 100 feet of material passed through was sand, gravel, and soft rock, and at a greater depth hard rock was penetrated, but no record as to its

nature, etc., is available. Two water-bearing strata are said to have been reached, one at 350 feet from the top, and the other at the horizon, where drilling was discontinued, namely, 840 feet. The outflow from the first water-bearing layer is said to have been small. The well is cased with iron tubing, 6 inches in diameter, to a depth, as reported, of 450 feet. The cost to Harney County was $2,400, not including the casing. The drilling was done by George W. Kellogg, of Salt Lake City, Utah. Work is said to have been abandoned on account of the loss of drilling tools in the well.

A well drilled on land belonging to Thomas McCormick, about 5 miles southeast of Burns, in sec. 12, T. 31 S., R. 24 E., completed in 1900, 6 inches in diameter, has a total depth of 68 feet. The water now rises to within 16 feet of the surface and yielded 100 gallons per hour by pumping. The material passed through was soft, and water is reported to have been reached in blue clay. The cost of drilling the well was $85 and of the casing $21.

Summary.—The evidence furnished by the drill holes in Harney Valley is meager, but so far as it goes it favors the hope that artesian water can be had throughout an extensive territory.

The well near Harney and the county well near Burns furnished flowing water and, I feel justified in affirming, would have continued to flow and to furnish a valuable water supply in each case had they been properly cased and cared for.

The well on Mr. McCormick's land is too shallow to be of significance in judging of the artesian conditions at the locality where it is situated.

Nearly all the evidence I have been able to gather in reference to the geological structure, the warm and hot springs, and the results of drilling certainly favor the conclusion that beneath the extensive plain east of Harney and Burns, on which Malheur and Harney lakes are situated, there is an artesian basin.

Conditions which may exert an adverse influence upon the value of the basin, so far as flowing wells are concerned, are the low pass on the northeast of Malheur Lake, through which the water of that lake formerly escaped, and the somewhat indefinite character of the rim of the basin to the south of Silver Lake. In addition are the "accidents" that may be present in any artesian basin, such as changes in the texture of the beds, the occurrence of breaks across the strata, and the presence of dikes.

In reference to the low pass which extends in an easterly direction from the flat country east of Malheur Lake through the hills to Camp Creek, it is evidently the lowest place in the rim of the Harney artesian basin and may perhaps determine the artesian head within the basin, but there are reasons for delaying a conclusion in this connection. The channel referred to is strongly defined and has a broad, level floor, formed by a recent basaltic lava flow. The bottom of the

previously cut river channel is thus concealed and is at least 20 to 30, and perhaps more, feet below the present surface. The highest point in the pass or old river bed (as shown, I have been informed, by surveys made with the view of drawing off the waters of Malheur Lake for irrigation purposes in Malheur Valley) is but 20 feet above the level of Malheur Lake. Evidently, then, the buried stream channel beneath the lava is lower than the broad valley lands about Malheur and Harney lakes and cuts across any porous bed that occupies the entire extent of the basin. If water-charged porous beds were cut by the channel, springs would be expected to occur in it. No springs are present, however, and it is possible that the silting over of the porous beds and the burial of the silt beneath lava has sealed them, so as to prevent the escape of water from them. While this is not such an indefinite hypothesis as it may at first seem, it does not remove all anxiety in reference to the influence of the old river channel referred to on the artesian conditions in Harney Valley. The question here raised can not be answered by the facts now known; neither can a positive opinion be expressed in reference to the position of the rocks to the southwest of Silver Lake, but my judgment is that neither of these possibly adverse conditions is of sufficient weight to discourage the drilling of test wells in Harney Valley.

From the elevations of the several localities at which warm and hot springs issue and of the surface of the two wells referred to above, the artesian head may be assumed to be at such an elevation that wells below the level of Harney or Burns would furnish a surface flow of water. The area of the basin below the horizon stated can not be accurately told at present, but embraces practically all the level land in Harney Valley about Malheur and Harney lakes and probably also the flat lands in the valley of Silver Creek and about Silver Lake. Extensive tracts of rich land in the region drained by Donner and Blitzen River are also within the area in which artesian water may reasonably be expected if drill holes properly cased are put down. A rough estimate based on the general map of Oregon, issued by the United States Land Office, indicates that the area within which artesian water may be expected is in the neighborhood of 1,000 square miles, but this includes Malheur and Harney lakes and the swamps bordering them.

To test the artesian conditions in the Harney basin, wells may be put down at any locality below the level of Burns or Harney. Perhaps the most favorable situations are near the warm and hot springs referred to, and at such places wells should be drilled on the side of the spring chosen, which is in the direction of the center of the basin or, in general, toward Malheur or Harney Lake. The depth to which wells should be drilled must be determined by experiment, as sufficient information is not in hand in reference to the sections exposed in the rim of the basin to warrant a judgment in this connection.

The successful well near Harney and Burns, however, suggests that favorable results may be expected anywhere in the basin below their surface elevation, at a depth of less than a thousand feet and possibly at a depth of only a few hundred feet. The possibilities of the basin, however, will not be exhausted when the drill has reached a depth of even 1,000 feet or, indeed, at a depth of 5 or 10 times that measure.

In the development of the basin an effort should be made to discover all of the water-bearing beds that are present within a reasonable distance below the surface, and in case several wells are drilled near each other, they should, so far as practicable, derive their water supply from different strata.

WHITEHORSE ARTESIAN BASIN.

Stein Mountain, as already stated, is the western slope of a great anticline. The central part of the upward fold referred to has been deeply eroded, and where faults occur, a subsidence has taken place. The position of the central and now deeply eroded portion of this great fold is occupied by Alvord Desert and the sharp-crested ridges running northeast from it. To the east of the Stein Mountain anticline or upward fold there is a flat-bottomed syncline or downward fold, in which Whitehorse Valley is situated. The rocks beneath this valley are bent into basin shape and the rim of the basin is high on all sides except the one adjacent to Alvord Valley. The rocks which have been bent so as to form a basin consist of reddish and brownish rhyolitic tuff in which angular fragments are conspicuous, black basalt, and light-colored and usually nearly white lacustral sediments and sheets of volcanic dust, resembling those characteristic of the Payette formation. The thickness of the beds exposed in the upraised rim of the basin—as, for example, in the mountains between Whitehorse Valley and Oregon Canyon, the next valley to the east—is several thousand feet. The bold bluffs on the west side of Oregon Canyon (which in the part here referred to is a broad valley with several ranches in its bottom) are formed of the edges of the sheets of rock, mostly basalt, which dip west and pass under Whitehorse Valley. Several springs issuing from the bluffs, well above their base, indicate that certain of the beds are water charged. These springs may reasonably be supposed to be the leakage from the basin to the west and suggest an abundant store of water beneath Whitehorse Valley.

In the southern part of Whitehorse Valley, about 6 miles south of the site of the former military post and at an elevation of fully 150 feet above the general level of the floor of the valley, there are springs with a temperature of about 100° F., which rise through soft white lake beds. In the northern part of the valley, about 10 miles north of the site of the former military post, as I have been informed, there is another warm or hot spring.

The facts stated above are such as to warrant a careful test of the artesian conditions in Whitehorse Valley. A boring should be made near the warm springs in the south end of the basin, a few rods north of the localities where their water now reaches the surface. A boring at Whitehorse ranch (the former military post) would probably yield flowing water, but the chances are nearly equally favorable all along the eastern side of the flat lands, which extend northward from the ranch for 10 or more miles. The area of good land within Whitehorse Valley, where it is reasonable to expect that flowing water can be obtained, is by a rough estimate not less than 30 square miles.

In the structure of the Whitehorse artesian basin there is one condition which may be detrimental to the occurrence of water in it under pressure, namely, the lowness of the rim of the basin on the west side in the vicinity of Sand Gap. The eroded borders of the beds emerging from beneath Whitehorse Valley there form a line of westward-facing bluffs, which define the east border of Alvord Desert. For the reason that there are no springs along the base of these bluffs, however, and for other reasons, the lowness of the rim of the basin need not be considered sufficiently important to deter the testing of the artesian conditions within it.

ARTESIAN WELLS IN ALLUVIAL DEPOSITS.

In regions like southern Idaho and eastern Oregon, which have an arid climate, and where bold mountains are bordered by wide valleys, the streams from the uplands deposit much and in many instances all of the sand, gravel, etc., which they bring down from the high-grade upper portions of their courses on the border of the valley which they enter. In this way alluvial cones or fans are built about the mouth of gorges where they open out onto a plain. These alluvial cones are not infrequently several miles in radius at the base and several hundred or perhaps 2,000 or 3,000 feet high. The apex of each cone is at the mouth of or some distance within the gorge from which the débris of which it is composed was derived, and from which a stream usually flows, at least during a part of each year. These beds of débris are thus in a position to become water charged, and their structure is such that pervious beds may be confined between impervious beds. Large alluvial cones may thus furnish conditions for the storage of water under pressure, and especially on the outer portion may yield flowing water if drill holes are put down.

Alluvial cones are sometimes greatly extended and have low surface slope, and in fact merge by insensible gradations into the flood plains of streams. This is frequently the case in arid regions, where the valleys are in many instances deeply filled with alluvium. Valleys when thus partially filled have broad, flat bottoms, with a perceptible gradient or surface slope down their courses. In such instances the surface material is usually fine, but becomes coarse at a depth of a

few feet or a few score feet below the surface, and as the beds are gently inclined the coarse beds at a depth may be charged with water under pressure. If flowing water is obtained by drilling in alluvial cones or flood-plain deposits it is normally cold, for the reason that it has not descended into the earth far enough to be influenced by the interior temperature of the earth. The water is similar to that supplied by hillside springs, and in Idaho and Oregon would have a temperature of about 50° F.

There are a few localities in the region examined by me in Idaho and Oregon where the conditions warrant the drilling of shallow wells in alluvial cones on flood plains. Some of these located in Idaho are mentioned in Bulletin 199, already referred to. In Oregon tests of the nature referred to should be made in Willow Creek Valley, to the northwest of Vale, and in neighboring flat-bottomed valleys which have a perceptible downstream slope.

The alluvial cones on the east side of Stein Mountain, at the mouths of gulches down which streams flow, should also be tested with the drill. The most promising localities for such tests are from the outer margin of a cone to midway up its slope. When the cones are steep, however, the chance of water being stored in them under pressure decreases rapidly as their summit portions are approached. The test referred to should be carried down to at least the level of the flat lands in the adjacent valley unless favorable results are sooner reached.

SIZE OF DRILL HOLES, THE CASING OF WELLS, ETC.

In the development of the artesian conditions of the Lewis artesian basin, as experience has already shown, light, portable drilling rigs will probably be all that are required, since the beds to be penetrated are soft. In the other artesian basins named, however, it seems highly desirable that only the most efficient of drilling machinery should be employed, as hard rocks will have to be penetrated in probably all wells that are more than a very few hundred feet deep. An extensive experience in drilling wells in the oil fields of the United States has shown that the best outfit for use in the artesian basins of Oregon is the square derrick walking-beam rig, provided with the best tools that can be procured. It is perhaps needless to add that only well drillers of wide experience and known integrity should be employed.

The wells to be put down should, in my opinion, be 8 inches in diameter, or drills of this size should be use to as great a depth as possible before tapering the hole to any smaller size.

In all instances the wells drilled should be well cased with iron casing. Neglect in this particular has led to failures in many instances in both Idaho and Oregon where success, as there are reasons for believing, would have been attained if proper casing had been put in. For the sake of emphasizing the statement just made, it may be truthfully said that water should not be expected to rise in a hole drilled

through rocks of various descriptions, many of them, as is usually the case, being porous, any more than it should be expected to remain in a standpipe full of holes rising above the surface of the ground. The water in an artesian well is under pressure—frequently great pressure—and tends to flow laterally wherever the rocks are porous or fissured. More than this, the walls of an uncased well are apt to cave and thus render useless all the work that has been expended on it.

In drilling a well the pressure of the water at each horizon where it is encountered should be carefully tested. One way of doing this is to lower a tube into the well, such, for example, as a three-fourths-inch iron pipe, with a leather bag filled with flaxseed encircling it near the lower end. The pipe should be lowered until its end is just above the place where water was struck. In such an experiment the flaxseed will swell and expand the bag containing it so as to shut off the escape of water about the outside of the pipe and allow it to rise within it. If the water overflows at the surface of the ground it demonstrates, of course, that an artesian flow has been secured, and if the pipe is continued upward the height to which the water rises within it will show the artesian head. Other suggestions in this connection may be found in a paper by Chamberlin, and in a report on Nez Perce County, No. 3 and No. 21, respectively, of the list at the end of this report.

Wells should be located as far apart as practicable, and when two or more water-bearing beds are present neighboring wells should have different depths, so as to draw their water supply from different sources. The distribution of wells in reference to the direction of flow of the underground water is also important. Obviously, if there is to be a series of wells, more or less in line, their alignment should be at right angles to the direction of underground flow, so as to decrease to a minimum the influence that one well exerts on its neighbor. Information in this connection is contained in the paper by Chamberlin, No. 3 of the list at the end of this report.

PRESERVATION OF WELL RECORDS.

If wells are drilled in the artesian basins described in this report a careful record of all facts concerning them should be preserved. This is a matter of great importance to all the people interested in the development of the artesian basins, and may lead to a great saving of money in other directions. As a practical method of obtaining and preserving information referred to, I wish to suggest that it be made the official duty of the county clerk in every county where drill holes are put down for any purpose to obtain and preserve a record of the facts relating to them. To assist in doing this a schedule is here inserted which can be printed, and which, after being filled in with the data required, should be filed at the county clerk's office for future reference. The schedule referred to is as follows (for greater convenience each item should be given a separate line):

WELL RECORD.

County, ——: State, ——.
County clerk, ——. No. ——. Date, ——. 190–.

Owner of well, ——. Driller of well, ——. Post-office address, ——. Location of well: Township ——, range ——, sec. ——. When completed, ——. How put down: Dug, driven, bored, drilled, ——. Size or diameter, ——. Depth: Total, —— feet; to water, —— feet; depth of water, —— feet. Did water rise when struck? ——. Does water flow over surface? ——. Height to which the water will rise in an open tube, ——. Has the flow diminished or increased? ——. Quality of water: Hard, soft, salty, alkaline, ——. Temperature of the water, ——. How is water raised? ——. Cost of well, $——. Cost of mill and pump, $——. Is the well cased? ——. Cost of casing, ——. Amount pumped or flow per hour or day, ——. Water used for ——. Elevation of surface, —— feet.

Strata passed through and remarks: ——.

LAWS.

As the water supply in an artesian basin may become of importance to a large number of citizens, it is obvious that laws governing its use are as necessary as the laws relating to surface waters, but, so far as I am aware, only one attempt to place legal restrictions on the utilization, or rather on the waste, of subsurface waters has been made in this country,[a] and that act fails in two particulars to meet the requirements outlined above—the proper casing of wells is not made obligatory, and the filling of abandoned wells is not provided for. Each of these regulations is highly important.

The principal restrictions and conditions which it is desirable should be established and enforced by law are as follows:

1. *Every drill hole in an artesian basin should be properly cased.*—By this is meant that an iron casing or tube lining the hole and made sufficiently tight to prevent water from rising outside of it should be put in every well which remains open. The lower end of the casing should be just above the water-bearing stratum.

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[a] The following law providing for the conservation of artesian water has been passed by the legislature of the State of Washington:

CHAPTER CXXI.

(H. B. No. 203.)

RELATING TO ARTESIAN WELLS.

AN ACT in relation to artesian wells and regulating the flow of water therefrom, and providing a penalty for the violation thereof.

Be it enacted by the legislature of the State of Washington:

SECTION 1. It shall be unlawful for any person, firm, corporation, or company having possession or control of any artesian wells within the State, whether as contractor, owner, lessee, agent, or manager, to allow or permit water to flow or escape from such well between the first day of October in any year and the first day of April next ensuing: *Provided*, That this act shall only apply to sections and communities wherein the use of water for the purpose of irrigation is necessary or customary, and providing further, that nothing herein contained shall prevent or prohibit the use of water from any such well between said first day of October and the first day of April next ensuing for household, stock, and domestic purposes only, water for said last-named purposes to be taken from such wells through a one-half inch stop and waste cock to be inserted in the piping of such well for that purpose.

SEC. 2. It shall be the duty of every person, firm, corporation, or company having possession

The reason why the owner of a well should be required by law to properly case it, as already explained in reference to the personal interest of the owner himself, is that lateral escape of the water may be prevented. The escape of water from an artesian basin in excess of the natural overflow means a decrease in pressure on the portions remaining, and consequently a lowering of the artesian head. In arid regions especially the sources of supply of an artesian basin may be small, and the question of economically using the water it contains and of maintaining the artesian head are matters of public concern.

2. *Every artesian well when not in use should be securely closed.*—The reason why a law to this effect should be enacted and enforced is that an artesian basin is not an inexhaustible reservoir, and every practicable means should be employed for its conservation and legitimate use. The closing of an artesian well when its water is not being used would in many and perhaps most instances be an advantage to its owner as well as to his neighbors, not only for the reason that his water supply would be made more permanent, but because water flowing over land in excess of the amount required for scientific irrigation is injurious.

There are exceptional cases in which it is not desirable that an artesian well should be closed at any time, as, for example, when a well is no more than a developed spring, or derives its water from what is known as an artesian slope,[a] but as such wells will probably be few in number in the artesian basins described in this report, special legislation in reference to them is perhaps not desirable.

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or control of any artesian well, as provided in section 1 of this act, to securely cap the same over on or before the first day of October in each and every year in such manner as to prevent the flow or escape of water therefrom, and to keep the same securely capped and prevent the flow or escape of water therefrom until the first day of April next ensuing: *Provided, however*, It shall and may be lawful for any such person, firm, corporation, or company to insert a one-half inch stop and waste cock in the piping of such well, and to take and use water therefrom through such stop and waste cock at any time for household, stock, or domestic purposes, but not otherwise.

SEC. 3. Any person, whether as owner, lessee, agent, or manager, having possession or control of any such well, violating the provisions of this act shall be deemed guilty of a misdemeanor, and upon conviction thereof shall be fined in any sum not exceeding two hundred dollars for each and every such offense, and the further sum of two hundred dollars for each ten days during which such violation shall continue.

SEC. 4. Whenever any person, firm, corporation, or company in possession or control of an artesian well shall fail to comply with the provisions of this act, any person, firm, corporation, or company lawfully in the possession of land situate adjacent to or in the vicinity or neighborhood of such well and within five miles thereof may enter upon the land upon which such well is situate, and take possession of such well from which water is allowed to flow or escape in violation of the provisions of section 1 of this act, and cap such well and shut in and secure the flow or escape of water therefrom, and the necessary expenses incurred in so doing shall constitute a lien upon said well, and a sufficient quantity of land surrounding the same for the convenient use and operation thereof, which lien may be foreclosed in a civil action in any court of competent jurisdiction, and the court in any such case shall allow the plaintiff a reasonable attorney's fee to be taxed as a part of the cost. This shall be in addition to the penalty provided for in section 3 of this act.

Passed the house March 7, 1901.

Passed the senate March 14, 1901.

Approved by the governor March 16, 1901.

[a] The nature of an artesian slope is explained in the report numbered 21 in the list at the end of this paper, page 112.

3. *Every abandoned drill hole in an artesian basin should be completely filled with impervious material.*—A desirable way in which to do this is to fill the hole slowly with moist clay and ram it down with a heavy, blunt tool, or fill the hole with Portland cement concrete. Tightly fitting rods of dry wood driven into a drill hole until it is filled would serve the same purpose.

Abandoned wells should be filled in the manner suggested in order that leakage may be prevented. Wells in which water rises some distance toward the surface but does not overflow are frequently abandoned, the casing, if any was used, having first been drawn, and in such instances a continuous escape of water occurs into cracks, porous beds, etc., about the hole.

The three rules briefly stated above should be embodied in the laws of every State in which artesian basins occur and their observance should be rigorously enforced.

For the proper development of an artesian basin it is evident that there should be but one center of responsibility. A desirable method of securing this end would be to place the entire control of the artesian wells in each State in the hands of a State engineer, whose duty it should be to determine where wells may be drilled, the depth to which they may be carried, and methods for caring for the water supply, closing abandoned drill holes, etc.

While the aim of this preliminary report is to stimulate and direct the search for artesian water in the region that has been considered, I do not wish to be understood as saying that all of the 2,000 or more square miles of rich lands contained in the four basins described can be irrigated by means of artesian water. The facts are plainly such as to warrant the careful testing of the artesian possibilities, but owing to local conditions, which are at present unknown, many difficulties will no doubt be encountered and numerous failures may occur, and even when all the wells which the water supply will justify have been put down in any one of the basins referred to there will no doubt remain extensive areas that can not be irrigated. While good results may reasonably be expected from the judicious development of the artesian basins, all the benefits that might be derived in that way will be rendered negative unless the suggestions given above in reference to the conservation of the water supply are strictly observed. I may perhaps add as a warning that the wanton destruction of the forests in this country and the now almost complete ruin of the public grazing lands throughout the arid regions leave but little hope that man's greed will be so far restricted in the case of artesian basins that ultimate failures will be avoided.

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Water-Supply and Irrigation Paper No. 79 Series L, Quality of Water, 5

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

NORMAL AND POLLUTED WATERS

IN

NORTHEASTERN UNITED STATES

BY

MARSHALL ORA LEIGHTON

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1903

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topography Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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Water-Supply and Irrigation Paper No. 79 Series L, Quality of Water, 5

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

NORMAL AND POLLUTED WATERS

IN

NORTHEASTERN UNITED STATES

BY

MARSHALL ORA LEIGHTON

WASHINGTON
GOVERNMENT PRINTING OFFICE
1903

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., November 13, 1902.

SIR: I have the honor to transmit herewith a manuscript entitled "Normal and polluted waters in Northeastern United States," prepared by Marshall O. Leighton, resident hydrographer, United States Geological Survey, and to request that it be published as one of the series of Water-Supply and Irrigation Papers.

This paper is principally a review of the more readily available records, published and unpublished, of examinations made of water supplies derived from streams in the northeastern part of the United States, the principal streams examined being the Merrimac, Connecticut, Housatonic, Delaware, and Ohio rivers, and the various important branches of the latter in the States of Pennsylvania and Ohio. It is, in effect, an account of the important work done in river examination up to the present date, a few unfinished inquiries now in progress being omitted.

The introduction treats of the characteristics of normal and polluted waters in general and seeks to explain, in language intelligible to those not versed in chemistry, the meaning and importance of the various determinations made in an ordinary water analysis. In dealing with the various rivers which have been subjected to examination, wherever the courts have been invoked to pass upon the legality of any existing state of pollution, or to adjust damages occasioned thereby, the cases are cited and pertinent excerpts are given from the decisions.

This paper forms one of a series of reports on examinations made as to the character of the natural waters of the United States and the pecuniary damage to municipal water supply occasioned by city and industrial wastes. It is expected that examinations of like nature will be undertaken by the Survey in cooperation with the various universities and State laboratories in the country, the character of the work differing according to the conditions and demands in each case.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey,
Washington, D. C.

NORMAL AND POLLUTED WATERS IN NORTHEASTERN UNITED STATES.

By M. O. Leighton.

INTRODUCTION.

In order to properly determine the water resources of a country, and to define the limitations of use which apply to various rivers, it becomes necessary to know the character of the water in each case. Water is a source of wealth by reason of the uses to which it may be put, and these are dependent to a large extent upon the nature of the water. It follows, then, that for each branch of water utilization there is established a standard to which water must reasonably conform, in order that it may properly fulfill the requirements of the particular case.

By reason of their physical features and their artificial development, different rivers may possess characteristics which make them very different in their form or kind of utility. Sewage pollution may destroy every resource of one river, yet may not sensibly affect the value of another. One stream may be highly useful as a source of power; another may be best utilized primarily as a commercial highway; still another may serve as a source of water supply. There are waters which are more valuable as a disposal area for manufacturing refuse than they would be if maintained unpolluted as fishing grounds or ice fields. Therefore a thorough hydrographic investigation should serve to indicate the peculiar uses to which a stream is best applicable, and by it we should be able to determine the normal resource in each case and the damage done by unwise or unlawful procedure. Of especial importance is the fact that the utilization of a river in one State may be so damaging to its purity that the people of another State through which the same river flows may be totally deprived of its use, and, under present conditions, with little if any opportunity for redress.

Let us glance briefly at the characteristics that are demanded of waters required for different uses.

ESSENTIAL QUALITIES OF WATER FOR VARIOUS USES.

Commercial highways.—The character of a water has nothing to do with its use as a means of transportation. For this purpose it is

only necessary that it shall be sufficient in amount to float vessels and that the course in which it runs shall be deep and broad and uninterrupted by impassable obstructions.

Power.—For utilization as a source of power a stream should have sufficient grade to allow the conservation of large quantities of water behind dams, so that it may be forcibly delivered upon water wheels, and, by means of the power developed by this impact, may operate mechanism applied to human purposes. If the gradient is abrupt—that is, if it is largely concentrated in one or several places, so that the water falls over precipices or runs in rapids—the power available will be greater and the expense of development will be less than if the fall of the stream is gentler or the stretches between rapids are longer. The constituents of a water used for the development of power are not of great importance except in such cases as its impounding by dams may be the means of holding back or depositing accumulated impurities which become a source of discomfort and thereby depreciate the value of real estate.

Manufacturing.—It is essential that a water used in manufacturing processes shall not contain anything which, from a chemical or sanitary standpoint, shall be injurious to the products of manufacture. The manufacturing uses to which water is put are very numerous, and when it is to become one of the constituent parts of the product it is necessary, in most cases, that it shall be pure and not liable to damage the product by reason of any substances which it may carry in solution or suspension. If, on the other hand, it is intended that the water shall be employed merely in the process of manufacture, as in washing products or in dissolving ingredients, it is readily apparent that foreign substances in the water may defeat this purpose.

Use in boilers.—Normal or pure water has a certain action upon metals, iron being one of those easily affected. If, therefore, a pure water is used in a boiler there must necessarily be some action which has its part in shortening the term of usefulness of the boiler. When a water is used which contains ingredients that hasten this action upon iron or which deposits sediments within the boiler, the usefulness of the boiler is shortened unduly, and the value of the water as a boiler water is lessened by an equivalent amount. An idea of the damage done by calcareous matter in water, which is deposited as an incrustation within the boiler, can be formed by considering the experience of the engineers on the Nebraska Division of the Union Pacific Railroad, where the water used held in solution a large quantity of sulphate of lime and magnesia. When such water is boiled the sulphate is deposited on the inside of the container. The expense of cleaning and repairing boilers by reason of this deposit amounted in two years to $2,860, equal to 8 cents per mile of distance run. In addition to this the total mileage of each engine was probably reduced one-half

Fisheries.—It requires only a slight study of the subject of fresh-water fisheries to appreciate how acute is the effect of water pollution upon the living organism. Many waters in the United States that were once good fishing grounds have, within recent years, become destitute of fish because of the dumping of wastes from factories or public sewers into lakes or rivers.

Nuclei of parks.—The development of park systems in this country is a striking revelation of a growing civilization. That there should be recognized, in this highly commercial atmosphere, the need of establishing pleasant places of rest, where the careworn citizen may escape for a short season from his business encumbrances, is a cause for gratification. No one has properly estimated the value of these shelters to the workingman, the isolated housewife, or the dust-stifled child. It is fast becoming the conviction of popular representatives that the people have a right to retain unto themselves certain convenient portions of the country in its natural state. Of such there could be many within easy reach of every city, but too often their establishment is made impossible by the foulness of the water flowing past available sites or standing close by in natural reservoirs. A body of pure water is the proper nucleus of such a place, for bathing, boating, fishing, and pleasant atmosphere are all necessary accompaniments of the perfect park. But in a place where bathing becomes suicide, boating resembles a voyage with Charon, and even breathing taxes the strong stomach, there is little prospect that a park will be established.

Ice supply.—The requirements of a water to be used as a source of ice supply closely resemble those hereinafter described with reference to water supply. The difference lies in the fact that a large proportion of foreign matter in water is excluded upon the formation of ice. Just how much is yet uncertain, but the most recent investigations show that the microorganisms which produce disease do not live long in ice.

Irrigation.—Water used for purposes of irrigation must contain none of the various mineral impurities, such as those found in manufacturing wastes, which are known to have a deleterious effect upon vegetation. This danger to irrigation is so remote as to be unworthy of a passing remark. Irrigation districts are not, and probably never will be, manufacturing ones.

Drinking water.—The standards set for a drinking water are more precise than those prescribed in any other branch of water utilization. Water is necessary to the continuance or even the existence of life, powerfully affecting human beings for better or for worse according to its character, and as the immediate preservation of human life is the principal object of society, this phase of the water question is more important than all those previously discussed.

It is not necessary that a water for public supply shall be chemically pure; indeed, such a water would be in many ways undesirable. Generally speaking, that which flows off or out of the land in its

natural state is usually well suited to the needs of man. If, however, in flowing out of a drainage area it becomes contaminated with the ejecta of man or of domestic animals; if into the courses in which it flows there is emptied the refuse from mills and factories; if upon the land drained by the stream there has been spread any animal refuse whatsoever, then the run-off water will be changed in character, and even though it may subsequently be treated, naturally or artificially, in such a manner that it is not prejudicial to health, it will bear to its final destination the marks of its former bad associations.

The value of a water is commonly reckoned according to its availability for public consumption. To be acceptable to the public it must have little or no turbidity and must contain little or no sediment or organic waste, color, taste, or odor. It will, therefore, be useful to follow the course of a quantity of water from its source in the ocean around its cycle of changes until it again reaches the ocean, in order to show how great are the obstacles that prevent it from meeting these several requirements.

IMPURITIES IN NATURAL WATERS.

RAIN WATER.

Water is raised by evaporation from oceans, lakes, ponds, and from the surface of the earth, and carried aloft, there to float in the form of clouds until the air sustaining it is saturated, when it is condensed and precipitated upon the earth. In falling through the air rain water naturally washes out any impurities held there in suspension. These impurities consist of dust composed of organic and mineral matter, such as pulverized earth, soot, pollen, and dried and finely divided particles of plants and insects, as well as ammonia, carbon dioxide, sulphuric acid and other gases, all of which are dissolved or held in suspension by water. Consequently when the rain strikes the earth it is not, as is commonly supposed, pure water. The amount of impurities it may contain depends on local conditions. If the air washed is that lying over a large manufacturing city it is manifest that the water on reaching the earth will be less pure than that falling upon a primeval region. Nevertheless, even in the latter case, the air always contains a certain amount of foreign matter. It is also manifest that rain water falling during the later part of a storm will be purer than that which first fell, for after a time the air will be cleared of its impurities.

On striking the earth, assuming that it falls on a mountain or on sloping land, there are several courses that water may take. Some of it is immediately absorbed by vegetation or directly evaporated from the earth's surface as it was from the ocean. The larger part, however, takes two other courses: (1) It runs directly off the surface in rivulets, converging into rills, streams, brooks, and rivers; (2) it sinks into the earth and, after filtering to a greater or less depth, reappears as springs or is intercepted by wells. Let us first follow that which runs directly along the surface of the earth.

SURFACE WATERS.

Some of the impurities which the water gathered in the air are lost as soon as it comes in contact with the earth, but in its course along the surface many more are gathered up—particles of sand or silt; pieces of dried or decayed leaves, wood, and grass; microscopic insects, and myriads of bits of other material of an almost imponderable nature which in the aggregate amount to a surprisingly large quantity. These particles ultimately are dissolved, or if sufficient time is not afforded to dissolve them they are deposited on the bottom of the stream in places where the current of the stream is checked. We have, therefore, the following classification of impurities in water:

Impurities in water.

- 1. Suspended matter
  - Inorganic or mineral — Sand, clay, and various pulverized minerals.
  - Organic
    - Animal: Living microscopic animals, dead fish and pieces thereof, feathers from birds, etc.; decayed animal refuse; manufacturing wastes, such as wool scourings, blood from slaughterhouses, etc.; excrement from sewers, etc.
    - Vegetable: Dried leaves, grass, and flowers, decayed wood, peaty matter; algæ and other plant life, including bacteria; wastes from cotton, silk, and linen mills, and from distilleries, etc.
- 2. Dissolved matter
  - Gaseous
    - Carbon dioxide.
    - Hydrogen disulphide.
  - Solid
    - Inorganic metals in general.
    - Organic
      - Animal (see above).
      - Vegetable (see above).

Organic matter.—Water as it passes over the earth, therefore, becomes more and more impure, the extent of its pollution depending on the character of the matter which it gathers up and carries along or which is poured into it by artificial means. Matter which is merely held in suspension would not seriously affect the character of water but for the phenomenon of solution, by reason of which the state of suspension is not permanent, for sooner or later a large part of the suspended matter is dissolved. It is a familiar sight to see inorganic matter dissolve in water, and the process seems simple; but the explanation of the solution of organic matter presents difficulties. How is it brought about? In order to explain this it will be necessary to discuss briefly the composition of organic matter.

Organic matter—that is, matter which is the product of life processes—consists chiefly of the four elements, carbon, oxygen, hydrogen, and nitrogen. These elements stand closely in union as long as life endures. Immediately upon the occurrence of death, however, there comes a breaking down. The chemical combination in the original living matter may be expressed thus:

Oxygen—Carbon
| × |
Hydrogen—Nitrogen.

When there is no longer a bond of union between the four elements there comes dissociation and a reuniting of elements having attraction one for the other. In this case one of the first steps in the breaking down of the above combination may be expressed as follows:

Oxygen—Carbon

Nitrogen—Hydrogen.

The oxygen in this and in the other processes here described is derived to only a limited extent from the decaying organic matter itself, but is drawn in large part from the atmosphere and from the store of oxygen suspended in the water. The oxygen and carbon combination, known as carbon dioxide or popularly as "carbonic acid," combines with other elements or goes into solution as such, and its connection with the old combination is permanently severed. The nitrogen and hydrogen combine and form ammonia. This completes the first step in the process. We have the organic matter, once in suspension, then in solution, now broken up into two very familiar compounds, both inorganic.

The process is not yet finished. The combination, nitrogen-hydrogen, is not a strong one. It is easily disturbed in several ways, and one of these is the introduction of more oxygen, which is nearly always present in water and always in air and in innumerable chemical combinations. Both of the above elements are more strongly attracted by oxygen than they are by each other, and therefore there is a further breaking up. The next step may be represented as follows:

Nitrogen—Oxygen—Hydrogen

Hydrogen—Oxygen.

Now the hydrogen-oxygen combination is water, a very stable compound, and therefore that portion of the hydrogen and oxygen which is combined as indicated in the diagram is permanently disposed of. No further change takes place in it. Not so with the nitrogen-oxygen-hydrogen. As it is first combined, one part of nitrogen and one part of hydrogen, hold together two parts of oxygen, so that the combination is more accurately expressed:

$$\text{Nitrogen} \left\{ \begin{array}{l} \text{Oxygen—Hydrogen.} \\ \text{Oxygen.} \end{array} \right.$$

This combination would remain stable if there were not more oxygen present and available. But as the element nitrogen can hold in combination three parts of oxygen, there can be no permanent chemical compound formed until this possibility is accomplished; so another change takes place, and the nitrogen finally holds three parts of oxygen, thus:

$$\text{Nitrogen} \left\{ \begin{array}{l} \text{Oxygen—Hydrogen.} \\ \text{Oxygen.} \\ \text{Oxygen.} \end{array} \right.$$

The first compound is one of the substances that are necessary to the formation of a nitrite; the second forms the foundation for a nitrate, the essential distinction between these consisting of a difference in the amount of oxygen present. A nitrite represents a very unstable, transitory combination, which takes place in the oxidation of organic matter, and which in any case is not permanent. A nitrate, however, represents the final condition of mineralized organic matter. It is the stage where the decay of that which was formerly living matter stops, when every chemical demand is satisfied. A nitrate is a permanent, stable compound which is not readily broken up nor acted on by other elements or compounds.

It must be remembered that the changes above described, as will hereafter be noted more fully, take place in the presence and by the action of living organisms, and while the processes roughly outlined are not so simple as has been indicated, the foregoing explanation will nevertheless, it is hoped, give a general idea of their character. As a concluding remark, it is sufficient to note that under the circumstances the condition of nitrogen in a water faithfully represents the condition of the organic matter in that water.

Bacteria.—Having traced the changes that take place in the organic matter of a surface water, let us now consider the means by which such changes are effected. In the list of organic materials above enumerated it will be remembered that bacteria found a place among those matters "suspended." It is by their agency that the changes above described take place. They are not the bacteria which are known to produce disease, but they belong to the great and useful species of the order. They are found primarily in the air and in the ground, and their presence is indispensable to the reduction of waste organic matters to the inorganic elements from which they are made up. Along with the pollen, the soot, and the fine particles of animal and vegetable matters in the air, these bacteria are collected by the rain falling to the earth. When they are brought to the earth in rainfall they immediately begin the work of changing the organic matter, and they are at once reenforced by the myriads which are always present in the ground. The greater the amount of organic matter carried along by the water, the greater the number of bacteria that gather to reduce it, so that the number of bacteria found in a water is an accurate measure of the amount of organic matter it contains. Their presence in large amount does not necessarily signify that the organic matter is dangerous, but the very fact that there is sufficient food to sustain great numbers of bacteria is sufficient indication that putrefactive processes are going on in the water, the true significance of which must be ascertained before the water should be accepted for domestic use. Animal matter is more highly putrefactive than vegetable matter, and, except under extraordinary conditions, a high number of bacteria is indicative of animal pollution.

Algæ.—There is another great branch of the plant kingdom which exerts a powerful influence upon the purification of surface waters: This is the group Algæ. These are the minute green plants which, in stagnant pools, grow in such large numbers as to occasionally form what is popularly known as a "scum" over the surface. These plants subsist upon the products of decomposition of organic matter. As soon as the bacteria succeed in breaking down the complex organic combination as above described, these algæ grow abundantly and feed upon the products of decomposition. As the change from ammonia to nitrites and nitrates is made, they continue to consume the débris, so that the tendency is to clear the water of such matter. If such a water were placed in a glass and no further pollution were allowed to enter, it would be found that after a short period the ammonia, nitrites, and nitrates would be greatly reduced. It is also true that the algæ themselves live to maturity and die, contributing more organic matter to the water. But, unless the conditions are such that an overabundant growth is induced, and the living algæ can not consume the débris of their dead ancestors, the supply of organic matter from this source is not such as to materially affect the condition of the water from the standpoint of total organic nitrogen.

These algæ ofttimes contribute odors, tastes, and color to the water as a result of their life processes and their decay, so that in all cases their presence is not wholly beneficial from a sanitary standpoint. Such odors and tastes are characteristic and can be readily detected. The action of algæ described above is not fully exerted unless the water is quiet, or practically so, for a short time, although there is no doubt that some action takes place in running streams.

Algæ also feed upon carbon dioxide set free by the action of bacteria upon organic matter. The recent studies along this line are very instructive, and seem to clear up an important point which has, for a long time, not been fully understood. The purifying process which has been supposed to exist in the extensive aeration of water, like that tumbling down over a cataract, has been found to have very little effect upon the state of organic matter in the water. Dr. Thomas M. Drown, in a memorable experiment, found that after air had been blown through water for an extended period very little change had resulted in the condition of the organic matter. The work served to emphasize the fact that bacteria are all important in the oxidation of organic matter, and that the process is distinctly different from the oxidation of an inert mineral substance. It was therefore believed that the splashing of a brook down the side of a mountain had no purifying effect. Recent work has shown, however, that this process is beneficial, not on account of the absorption of oxygen in the water, but by reason of the expulsion of the carbon dioxide from it, so that the algæ, deprived of a large part of their food, would not be likely to grow to an extent that would make their presence objectionable.

Disease germs.—There is one other requirement demanded of a drinking water which, although inseparably linked with much that has gone before, must nevertheless be treated by itself. This requirement is, that a water used for domestic purposes shall not contain the specific germs or bacteria of ground-borne diseases, such as typhoid fever and cholera. It has been stated that in all waters in which the decomposition of organic matter is going on there are bacteria, which are requisite to the furtherance of this decomposition. It has also been shown that, although these bacteria are not productive of any specific disease, their presence in large numbers in a given water is a satisfactory indication that there must be a correspondingly large amount of decaying matter in the water to provide them sustenance. Experience has shown that a water which during a long series of examinations shows an average of more than 150 to 200 bacteria per cubic centimeter merits careful investigation. The presence of disease-producing bacteria is a matter which requires special consideration.

The bacterium commonly occurring in the United States is the bacillus of typhoid fever. This disease has its seat in the human intestine, and the infective material is naturally ejected during the course of the disease, and is carried along through sewers to the place of disposal. If this is a river the water therein becomes infected with germs of this disease, and the infection is communicated to persons drinking the water farther down the course. It is well known that the natural habitat of these bacteria is not in water, and therefore their life is not continued for a long period. Just how long this period is, however, is very uncertain; it surely has no connection with the period required to mineralize organic matter. Therefore the absence of the latter in its unoxidized state is no guaranty that dangerous bacteria are not absent. Their term of life probably varies widely, depending upon the local conditions, temporary or permanent.

UNDERGROUND WATERS.

Heretofore we have considered only that part of the water of precipitation which, upon striking the earth, flows directly off the surface into streams. That part which sinks into the ground is of equal importance, for it constitutes the reserve supply from which streams are replenished after the influx due to a rainfall has spent itself. All ground waters must at some time issue from the ground in the form of springs, wells, etc., and, flowing along in courses, become surface waters.

Basis of interpretation.—The fitness of ground water for public supply must be determined in ways very different from those used in determining the potability of surface waters. When rain water sinks into the earth it meets conditions which are highly favorable to the oxidation of the organic matter it contains. The water sinks slowly down through the particles of sand, the faces of which are covered

with the bacteria that bring about oxidation. Under such conditions an enormous extent of bacterial surface is exposed to the water, and the change of the organic matter from albuminoid ammonia to nitrates is exceedingly rapid and complete. Consequently, when such water emerges from the ground it is to be expected that the amount of ammonia and nitrates will be exceedingly small or absolutely wanting. When a spring water is found which possesses these ingredients, it is practically certain either that the water was originally a surface water which, upon entering the earth, has quickly passed below the layer of available oxygen in the ground, so that the normal process of decay has been retarded, or, having been once freed from its organic matter, has become contaminated with the contents of some sewer, cesspool, drain, or other source of waste matter. It is not an easy task to discriminate between these two possibilities unless there is at the disposal of the investigator a table or chart showing the amount of normal chlorine of the water of the locality within which the spring is located. With such information at hand, it is necessary only to compare the amount of chlorine found with the normal amount for the locality to ascertain whether the contamination is local or arises from natural phenomena. It has therefore become the practice of sanitarians to demand that a ground water shall contain little or no unoxidized organic matter. The amount of nitrates found in such a water is nearly always large, sometimes rising, in perfectly safe waters, to a very high proportion. Such results indicate an extensive previous pollution, which has been thoroughly cleared up. The element of danger in waters of this kind is the possibility that there might at some time be such a change in conditions controlling this oxidation that the process would fail of completeness.

Storage of ground waters.—When ground waters are stored in reservoirs in the presence of sunlight there is a quick and profuse growth of algæ in the basin, due to the abundant presence of nitrates which serve for food. Under such circumstances it is necessary to cover the reservoirs when it is desired to preserve ground waters in their original state.

SANITARY ANALYSES.

It will now be instructive to consider sanitary analyses and their significance. A sanitary analysis of water is not the determination of its mineral constituents and the quantity of each, but consists of the observation of a few physical characteristics, such as color, turbidity, odor, etc., and a determination of the different forms of nitrogen it contains, the amount of which, as has been remarked, is a faithful representative of the character of the organic matter in the water. It should be distinctly borne in mind that the ingredients which are determined in such an analysis are not harmful of themselves, and, as such, have no significance whatever. They are simply

guideboards which point out the way to a knowledge of the true condition of the water.

In Table 1 is given an analysis of a normal water in the State of Massachusetts.

TABLE 1.—*Analysis of a normal water from Massachusetts.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5

Turbidity.—The term "turbidity," in the first column, defines itself, and in the analysis above set forth the degree of turbidity is expressed by the word "decided." The terms here used to express various degrees of turbidity, from lowest to highest, are as follows: "Very slight," "slight," "distinct," and "decided." This nomenclature is now used in only a few laboratories. In more recent analytical procedure turbidity is expressed according to a standard scale, the details of which are described in Circular No. 8 of the Division of Hydrography of the United States Geological Survey.

There are several highly important reasons for knowing turbidity, which make necessary the fine adjustment of an apparatus for its determination. Turbidity is a physical condition of water which must be measured by comparison with standards which are arbitrarily adopted. A clear water is most acceptable as a beverage. The most slovenly of mankind have an inherent dislike for a turbid draft, and even horses refuse to drink a water of doubtful appearance. Turbidity is the result of various causes, and a trained observer can infer a surprising number of facts concerning the history of a water and the condition of the area from which it comes by a superficial survey of the visible foreign matter held in suspension. A highly turbid water is unsuitable for many domestic and manufacturing purposes, and therefore the accurate determination of the degree of turbidity at the beginning of an investigation in some cases obviates the necessity of further work.

Odor.—The determination of the odor of waters is important, as from it we can sometimes determine the origin of the water or the pollution which it contains. Odors are often imparted to water by the green plants which grow in it, sometimes to a disagreeable extent. For a description of the method of describing odor, reference should be made to Circular 9 of the Division of Hydrography.

Color.—Returning to the analysis above set forth, the color denoted as 6.0 means that, compared with an arbitrary standard, prepared

and adopted as such, this sample bears the relation of 6 to 1,000,000; that is, a standard brown color having been determined upon, the sample under investigation is compared with known dilutions of the standard, and the dilution having the tint nearest to the sample is the one which designates the color of the water.

Nitrogen.—The next division of the analysis is entitled "nitrogen," and is subdivided into "albuminoid ammonia," "free ammonia," "nitrites," and "nitrates."

Albuminoid ammonia.—Albuminoid ammonia represents the nitrogen in the original combination referred to above; that is, before decomposition has set in. From the results of the determination of the amount of albuminoid ammonia in a sample of water we can infer with a fair degree of accuracy the amount of organic matter it contains. This does not, however, give any clue as to the character of the organic matter, whether animal or vegetable. We may find in a polluted water a smaller amount of this ingredient than may exist in a normal water perfectly acceptable for drinking purposes. In the analysis reported above is set down a comparatively large amount of albuminoid ammonia. 1.252 parts per million; this water, however, is unpolluted by dangerous wastes. On the other hand, in several waters the nature of which is known to be very dangerous, there were found only 0.284, 0.196, 0.198, 0.262, and 0.263 parts per million. The determination reveals, then, only the quantity of organic matter present, and in order to decide whether it is of a dangerous nature or not we must look further. If it is found that the organic material is principally vegetable matter, which is far less susceptible to decay than animal matter, the water which contains it may be fit for household purposes if the taste, color, odor, etc., are acceptable. This, however, can not be determined by analysis, but must be the result of inspection of the water course.

Free ammonia.—Free ammonia is the product of the first process of decay of organic matter. Its presence, as such, in a water is not more harmful than that of albuminoid ammonia. It denotes that decomposition is incomplete; that it has been arrested or retarded. It is not necessary, nor, indeed, natural, that any considerable inhibition of the process of decay should take place, and when such retardation occurs, as is shown by a high proportion of free ammonia, there must be some cause for it. We have said that a controlling factor in this process of oxidation is the presence of oxygen. Now, if a water contain a large amount of organic matter in a putrescible state, its breaking down into carbon dioxide and ammonia may go on so rapidly that it consumes all or nearly all of the available oxygen. This is certainly the case with sewage, in which there is a large amount of organic matter undergoing rapid decomposition. In the following reports of analyses this is well illustrated. The first is a repetition of what is found on page 23, while the second is that of a polluted water.

TABLE 2.—*Analyses of a normal and a polluted water from Massachusetts.*

[Parts per million.]

Character of water.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Normal	Decided	6.0	1.252	0.000	0.000	0.000	1.1	51.5
Polluted	Slight	1.5	.263	.664	.025	.800	24.1	127.0

It will be seen upon examination of the above that in the polluted water the turbidity is less than in the normal water, the color considerably less, the total residue smaller in amount, and the albuminoid ammonia only 22 per cent of that in the normal water. When, however, we observe the comparative amounts of free ammonia, we find that in the unpolluted water there is none, while in the other there are 0.664 parts per million. This satisfactorily bears out the statements made in the preceding paragraph. It is evident that although the albuminoid ammonia in the polluted water has been so oxidized that the amount remaining can not be regarded as high, the free ammonia has not decreased in proportion. The cause of this must therefore be that the organic matter in the polluted water is so readily decomposed that it has consumed or was consuming all the available oxygen at the time the analysis was made. The fact that in the normal water there is reported no free ammonia indicates one of two conditions: (1) Either that algæ have consumed, as food, all the free ammonia as fast as it has been made, or (2) that the organic matter is not readily oxidized. We shall consider further on just which is the most likely deduction. High free ammonia may therefore be an indication of sewage pollution; at any rate it implies a rapid decomposition of organic matter.

Nitrites.—The presence of nitrites in a water is another indication of the incomplete oxidation of organic matter. It is only one step further in the process of oxidation, and as such, it must bear much the same significance as the presence of free ammonia. A nitrite is an even less stable condition of nitrogen than free ammonia; in fact, it represents nothing more than a short period of transition between free ammonia and the nitrates. Even in sewage-polluted waters it does not occur in so large a proportion as do the other forms of nitrogen. Rapid indeed must be the initial stage of oxidation of organic matter in order to allow the accumulation of nitrites. According to the analyses reported in Table 2 there are no nitrites contained in the normal water, but there are 0.025 parts per million in the polluted sample. The latter amount may be regarded as extremely high, and, taken with the high free ammonia, is almost certainly due to sewage pollution.

Nitrates.—The nitrates found in a water represent the complete mineralization of organic matter. When such matter, from whatever source derived, has reached this state it is entirely harmless. This is by no means equivalent to saying that a water with a high amount of nitrates and an insignificant quantity of the other forms of nitrogen is safe for drinking. There is no necessary connection between the amount of nitrates and the good or bad qualities of the water for public use. The question of the presence of the specific germs of disease is all-important and will be hereinafter considered. The presence of nitrates in a water, therefore, indicates nothing more than "previous sewage contamination." Of itself it is quite insignificant, but, taken into consideration with the determinations heretofore discussed, forms the final link in the chain which secures for us a knowledge of the history of a water under examination.

On referring again to the two analyses in Table 2 it will be noted that the amount of nitrates in the polluted water is large, indicating previous pollution. Yet it does not in any sense indicate that that pollution was dangerous. The report of analysis of the normal water shows that there are no nitrates. This is both uncommon and interesting. The amount of albuminoid ammonia in this sample is large, and under ordinary circumstances we might reasonably expect that there would appear at least a characteristic amount of the end product—nitrates. But as none appears we must conclude from the analysis that the organic matter in the water is of a kind that resists decomposition, and that as fast as the process is accomplished the algæ consume the ammonia, so that none appears in the various stages of oxidation.

Chlorine.—Little or no mention has been made of this substance in the previous pages in order that the discussion of the changes which take place in organic matter might not be complicated by other considerations. Few if any determinations in the whole range of water analysis are as important as that of chlorine. It bears absolute testimony concerning the history of the water, and its interpretation is dependent upon none of the other determinations. It may be under certain circumstances the crucial test by which a water may be accepted or rejected for potable use.

It is well known that chloride—that is, a chemical combination of chlorine with another element of a certain class, such as silver, magnesium, potassium, or sodium—are found in the earth in quantities varying according to the chemical nature of the geological formations. The most common of these is sodium chloride, familiarly known as common salt. These substances dissolve in water, some readily, others slowly, so that water that has passed through or over the ground is nearly always found to contain chlorides, generally common salt. Salt is found in the air, especially near the seacoast, and is one of the component parts of organic matter. The water

which flows over the surface of the land bears onward to the ocean an appreciable amount of salt in solution, a fact which is attested in a familiar manner by the saltness of the ocean and some of our great lakes which have no outlet. The wind blowing over the sea, driving it into spray, raises fine particles of salt, which are carried through the air over the land. These particles, being brought down by the rain, influence the amount of salt which is found in normal waters.

The work of the Massachusetts State Board of Health in the determination of the amount of common salt in normal waters has become classical. In a long series of analyses of normal waters selected in every part of the State it was found that there are distinct regions in which the amount of salt does not vary, except within very narrow limits, and that areas of equal normal chlorine may be defined upon a map of the State. It was found that the boundary lines of such districts follow roughly the coast line, and as the coast is receded from the amount of salt in normal waters grows less. This work has been taken up in Connecticut, Vermont, New Jersey, Ohio, and various other States. (See fig. 1.) How is such a map to be put to practical use? Before considering this question it will be necessary to take up the matter of significance of common salt in surface waters.

Common salt is composed of sodium and chlorine in equal proportions. Therefore, if it is desired to determine the amount of salt in a given water, it is only necessary to isolate one of these elements and the amount found will represent the whole. It is, for known chemical reasons, better to determine the chlorine, and therefore in an analysis of water like that in Table 1 the column "chlorine" represents the amount of chlorides, usually common salt.

We have said that salt is one of the component parts of both animal and vegetable matter. When a surface water is collected into a stream it contains chlorine that has been derived from vegetation as well as from the air and earth. Now, the amount of chlorine to be gathered from the vegetation of a district is as constant as that derived from the air or ground. When, however, animal matter is poured into the water there is an immediate rise in the amount of chlorine, which, obviously, can not be accounted for by any change in the natural conditions of the drainage area. It is clearly a contribution from sources other than those normally existing. The waste products of man, such as urine and fæces, and of the household, such as garbage and wash water, contain large amounts of salt, and when such waste is turned into a river its presence is easily detected. Now, the use of a normal chlorine map becomes apparent; whenever the water from any district is analyzed it is only necessary to compare the content of chlorine found with the normal content for that district, as shown on the map, and if the analysis shows a higher amount there is only one deduction to be made—that is, the water is or has been polluted with sewage.

When chlorine is once introduced into a water it remains there throughout the journey to the sea, accumulating according to the normal content of the country or the pollution introduced. The organic matter may be completely oxidized, generations of algæ may mature and die, color, hardness, turbidity, odor, and all else may change, but chlorine remains fast. Public sewers may be introduced into a river and change it to a stream of reeking filth; miles may afterwards be traversed; sedimentation, oxidation, and the most subtle filtration may take place, and the water may again be suitable for drinking, yet the actual amount of chlorine carried along by the stream does not, under usual circumstances, decrease appreciably. It may appear in smaller proportion at one point than at another, but

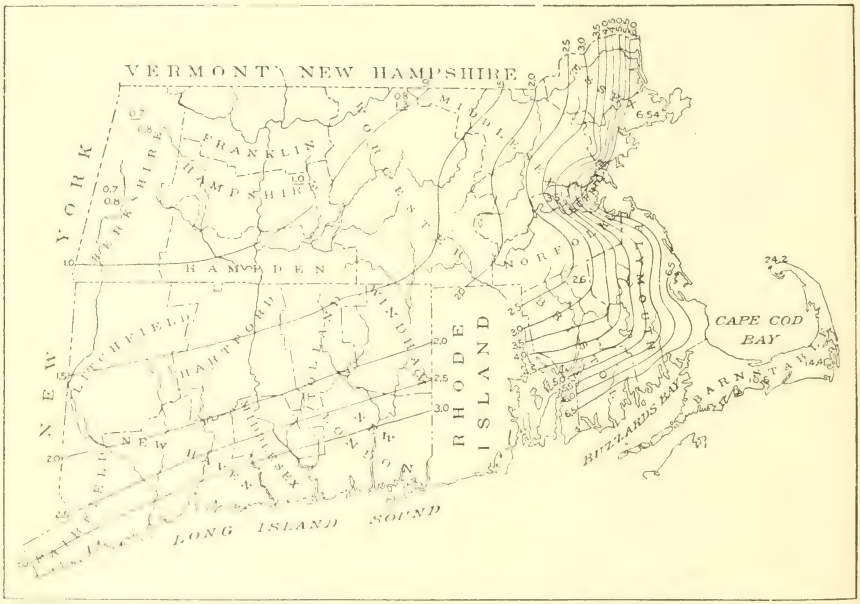

Fig. 1. Normal chlorine map of Massachusetts and Connecticut.

not by reason of any reduction of the actual amount of chlorine. To illustrate, the water of the Blackstone River just below the Worcester precipitation works contained in the year 1900 an average of 15.7 parts of chlorine per million; after flowing a few miles to Uxbridge it contained 13.8 parts, and finally at Millville, a short distance above the State line, it contained only 9.3 parts. The river in its progress from Worcester to Millville receives a comparatively large amount of pure water from its tributaries, also a large amount of pollution from different establishments along its course, but the amount of sewage added is in no way proportional to the amount of pure water contributed. Therefore the proportion of chlorine to water must grow less all along the course from Worcester to Millville. It is obvious that the

proportion of chlorine is never reduced to an amount equal to the normal, and therefore must bear evidence of former abuse. The abnormal chlorine in a water may be likened to the scar left from some ugly wound; although the parts may be united and the surrounding tissues be healthy, yet the mark of former injury can never be effaced.

Total residue.—Under "Total residue" are included all matters, organic or mineral, which serve to pollute the water. In the above analysis it means that if 1,000,000 parts of water were evaporated there would remain in the container 51.5 parts of residue, which would represent practically the weight of the total impurity.

Analyses of normal and polluted waters.—The following analyses of normal and polluted waters, taken from the special report upon the "Examination of water supplies," made by the Massachusetts State Board of Health in 1890, are very useful in illustrating the principles above set forth. The first set of analyses represents normal waters and the second polluted waters.

TABLE 3.—*Analyses of normal and polluted waters.*

[Parts per million.]

No.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
NORMAL WATER.								
1	None	0	0.022	0.000	0.000	0.060	0.8	50.0
2	Decided	1	.702	.000	.006	.030	1.0	25.0
3	do	6	1.252	.000	.000	.000	1.1	51.5
4	Slight	4	.333	.130	.001	.250	1.6	36.5
5	do	3	.136	.000	.000	.050	6.3	32.5
6	do	0	.152	.000	.000	.060	21.0	59.5
POLLUTED WATER.								
7	Distinct	1	0.284	0.124	0.009	0.150	1.9	107.5
8	Very slight	5.5	.196	.000	.004	.550	5.4	51.5
9	Distinct	1.0	.198	.016	.004	.200	5.8	50.0
10	Slight	1.5	.262	.000	.010	.170	20.9	102.5
11	do	1.5	.263	.664	.025	.800	24.1	127.0

Careful examination of the above table shows that chemical analyses alone may furnish very little information concerning the healthfulness of a water unless certain matters determined are in exceedingly high

proportion. Analysis 11, in Table 3, for instance, is such that a person could, with a fair degree of safety, condemn the water. The free ammonia, nitrites, and chlorine are high, giving evidence which is unmistakable. Sewage is poured into the body of water from which this sample is taken.

Supposing, however, this series of analyses was not divided into "normal" and "polluted," how would we be able to place 8 in its proper position under "polluted waters?" The results of the determinations in this analysis appear lower than some of those in the normal list. On comparing it with 4, for instance, it will be seen that in the polluted water the turbidity is less, the color not much more, the total amount of organic matter not greatly different. The free and albuminoid ammonia are much less in the polluted water; the nitrites are considerably more, but not so great as in normal water 2. The nitrates are higher, but this, as has been explained, means little so far as the healthfulness of the water is concerned. The marked difference in the two seems to be in the amount of chlorine, but if we glance at the normal chlorine map (fig. 1) it will be seen that if 8 were collected in the region of Boston and 4 were collected farther west, these amounts of chlorine would both be normal. If we do not know where they were collected or whether the nitrogen compounds are the result of decomposition of harmless vegetable matter or dangerous animal waste, the bare water analyses are nearly worthless; but taken in connection with a knowledge of the locality, population, and sewerage conditions within the drainage area, the analyses are preeminently useful in determining the conditions of the water.

Hardness.—Some of the damages done by the use of hard water have already been referred to under the title "Use in boilers" (p. 14). In a public supply a hard water is troublesome and expensive by reason of the fact that when it is used for household washing it requires a larger amount of soap to produce the desired result. The fatty acids in the soap must first neutralize the calcareous matter in the water before it can be used for washing. A uniform scale for the determination of hardness is at present the subject of considerable thought among water analysts. The present methods, however, are efficient to a certain degree of accuracy and enable us to distinguish a soft water from a hard one.

There are two grades or kinds of hardness which will, wherever possible, be distinguished in the following pages. The first is due to the presence of alkaline carbonates, such as calcium, sodium, and magnesium carbonates. When water containing these compounds is boiled their effect quickly passes off; consequently it is designated as "temporary hardness," or, as it will be termed in this review, "alkalinity." The second grade of hardness is due to the presence of alkaline sulphates, chlorides, and nitrates. They do not disappear upon

boiling, and therefore maintain a "permanent hardness" or "normal hardness."

In the succeeding pages, in the case of New England, where the total hardness—that is, both temporary and permanent together—has been determined, the amounts indicating the degree of hardness are the result of a reduction of the amounts of all alkaline earth salts to terms of an equivalent amount of carbonate of lime. In other words, in Table 7 the statement of the hardness as 11 means that the water contains an amount of alkaline salts which make it as hard as would have been produced by 11 parts of carbonate of lime per million. In the statement of the hardness in the case of waters in the Ohio Basin, on the other hand, where the hardness is divided into "temporary" and "permanent," the temporary hardness indicates the amount of alkaline carbonates reduced to an equivalent of calcium carbonate; and in the case of permanent hardness, the amounts include the alkaline sulphates, chlorides, and nitrates reduced to an equivalent of calcium carbonate.

Summary.—In the preceding pages an attempt has been made to briefly and plainly state the characteristics demanded of a water required for public and household uses. Many details have been purposely omitted, but it is believed that enough has been said to enable the reader to comprehend the changes that take place in the dangerous or undesirable ingredients common to water supplies, a knowledge of which is necessary to a proper understanding of the contents of the following pages.

POLLUTION OF NATURAL WATERS.

The pollution of natural waters, though it may be sometimes unavoidable, is usually highly damaging to the resources of the country in which it takes place. The matter is a troublesome one in populous countries and has occupied the attention of chemists, engineers, land promoters, and others, as well as of courts of law, having been a fruitful source of litigation. The basis of action in all cases of this character is founded on the principles of common law in respect of the ownership of real property. The title of a land owner presumptively extends upward to the clouds and downward to the earth's center, embracing everything upon the surface and beneath it. This includes the mineral wealth in the ground and arising out of it, such as coal, iron, copper, oil, water, and even gas. The water flowing from a spring situated upon a certain piece of property belongs to the owner of the land as truly as do the blades of grass that grow upon it. A water right, whether it be vested in a spring, well, or river, is appurtenant to the land and passes with it by conveyance. The ownership so secured carries with it the assurance that all water passing out of or over the property shall be normal, and that any pollution

other than that caused by the natural drainage of occupied land lying above is actionable in law.

The situation is well summed up in a few paragraphs from the American and English Encyclopedia of Law, volume 28, under the heading "Water courses:"

Riparian rights are the correlative rights of adjoining proprietors upon the banks of water courses with respect to the water thereof. * * * The property in the water is indivisible, and all proprietors are entitled to an equality of rights therein.

In consequence of the common right of riparian proprietors to the benefits of water flowing through their land the general rule is that no proprietor has the right to use the water to the prejudice of another. This principle, however, does not restrain the use of the waters, so that there can be no diminution or impediment whatever, but the true measure and standard of the use which a riparian owner may make of his right is the reasonableness thereof. Each is entitled to a reasonable use for domestic, agricultural, and manufacturing purposes. * * * reasonable with respect to the rights of others.

A right to a reasonable use includes the right to release, let down, and discharge waters in order beneficially to employ them; and the exercise of the right entails no liability for injuries necessarily caused thereby to others in regard to the rise of the stream; yet if the discharge withdraws from another the use of the waters to which he is entitled, or if it needlessly deprives another of his beneficial use, or injures or destroys another's property, a case for damages is presented.

The right to the reasonable use of the water of a stream not navigable that flows through ones land includes the right to confine and obstruct its flow with dams in order to utilize the water power, or, for other beneficial purposes, to detain the water for such a length of time as it may be reasonably necessary for such use, notwithstanding the detention injuriously interferes with another's exercise of his right to the reasonable use of the stream in its natural state.

The right of every owner of land through which a stream of water flows to have the same flow in its natural state extends to the quality as well as the quantity of water, and therefore one who pollutes or contaminates water may be liable to those injured thereby, and a court of equity will interfere by injunction to restrain such use as will cause an irreparable damage or endanger the complainant's rights by adverse possession if continued.

A frequent ground of action arises from the operation of mills and factories, the refuse from which poisons, corrupts, and renders unwholesome the waters of a stream, or in some other way impairs it usefulness. The deposit of dyestuffs, whereby a stream is polluted or discolored; the discharge of poisonous or corrosive substances into a stream, whereby the machinery of lower riparian owners has been injured; emptying offensive matters from tanyards, and deposits of sawdust waste or refuse of mills to the injury of lower proprietors, have been held to be actionable and proper grounds for injunction.

A riparian proprietor who pollutes a stream by an unreasonable discharge of sewage, to the injury and inconvenience of lower riparian owners, is liable for damages therefor. If a muncipal corporation causes sewage to pollute a water course, to the use of which a lower landowner through whose premises it passes is entitled, it is guilty of a nuisance, for which damages may be recovered.

It appears, then, that there is no legal justification for the pollution of water, yet so universal is the practice that it has come to receive moral justification at the hands of society and meets no general con-

demnation except in cases where it goes beyond the bounds of human endurance. A few States in the Union have recognized the damage arising from water pollution and have made intelligent investigations for the purpose of correcting the evil. The results of some of these investigations will be presented in the following pages, together with the results of examinations made by several towns and cities as a consequence of local necessities. The data are arranged according to drainage areas, and in the case of interstate rivers, where the work has occurred in several States, the results obtained for a particular stream will be combined.

MERRIMAC RIVER BASIN.

GENERAL FEATURES AND METHODS OF UTILIZATION.

Course and drainage area.—The Merrimac drainage basin is 4,553 square miles in extent. (See fig. 2.) It is situated in New Hampshire and Massachusetts, occupying in the latter State 1,136 square miles. The Merrimac River proper is formed by the junction of the Winnepesaukee and Pemigewasset rivers at Franklin, N. H., from which place to its mouth, at Newburyport, Mass., it is about 110 miles long. From Franklin it takes a south-southeasterly course until it passes for a short distance into Massachusetts, when it abruptly turns northeastward and enters the Atlantic Ocean.

There is a wide variation in the physical characters of the Merrimac Basin. A large part of it is highly cultivated and fertile, but at the headwaters of the different tributaries the country is exceedingly rough and rugged. A small part of the area is low and swampy. Forests worthy of the name are almost entirely wanting in large parts of the basin, their absence causing a certain inconstancy in the flow of the river, but this has been in a measure corrected by a thorough system of storage, natural and artificial.

Throughout the basin the underlying rock is largely granite, which furnishes a valuable source of supply for building materials.

Storage.—Within the drainage area of the Merrimac are many lakes, ponds, and artificial reservoirs which afford excellent storage, and, as has been stated, compensate in a measure for the effects of extensive deforestation. The most important of these are Lake Winnepesaukee and Long Bay, covering 71.75 square miles; Squam, New Found, Belmont, and Massabesic lakes, Smiths and Suncook ponds, and a long chain of reservoirs in Massachusetts, which conserve a water supply for the "Metropolitan district."

Transportation.—The river is not important as a means of transportation. Small coastwise vessels may ascend as far as Haverhill only, and the amount of traffic is not large.

Power.—As a source of water power the Merrimac throughout its

whole extent is justly famous. In the main river there is a total fall of 269 feet in 110 miles, an average of 2.45 feet per mile. This fall, however, is concentrated at six principal points, giving most advan-

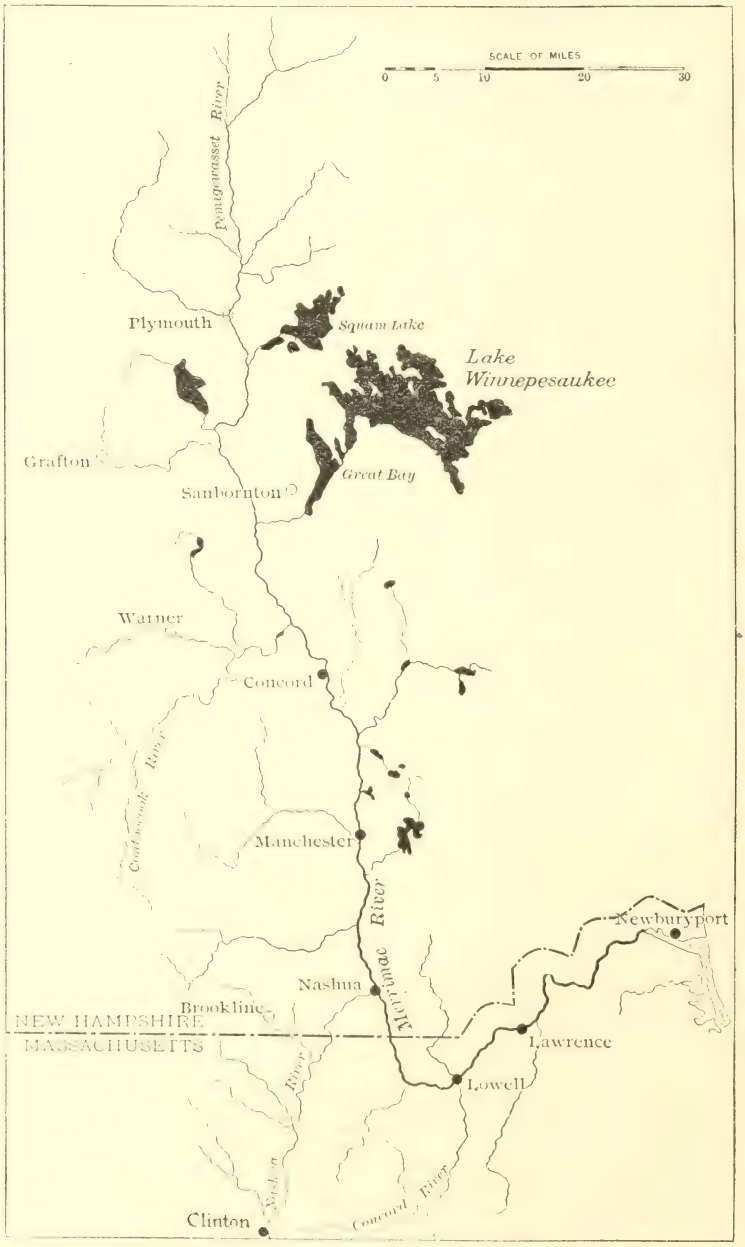

FIG. 2.—Merrimac River drainage basin.

tageous power facilities. Up to the present time there have been utilized over 40,000 horsepower at Lowell, Lawrence, and Manchester.

On the tributaries, too, there are a large number of power sites, which have been utilized extensively. In Table 4 is given the total utilized horsepower on each important tributary. Some of these, especially in the drainage area of the Concord and Nashua rivers, have been abandoned to make way for the metropolitan water-supply system.

TABLE 4.—*Utilized horsepower of tributaries of Merrimac River.*

Branch.	Total utilized horsepower.	Drainage area (square miles).
Powwow River	1,850	50
Shawsheen River	645	72
Spickett River	701	79
Beaver Brook	687	92
Concord River	4,962	380
Stony Brook	904	35
Nashua River	11,762	516
Souhegan River	2,451	224
Cohas Brook	170	44
Piscataquog River	1,250	214
Suncook River	2,881	264
Soucook River	72	90
Contoocook River	6,360	766
Winnepesaukee River	6,503	480
Pemigewasset River	4,114	1,013
Total	45,312	...

Ice.—With the exception of Lake Winnepesaukee there are no very large ice fields within the Merrimac drainage area. Taken collectively, however, the ice industry is very large, each pond or lake which has remained sufficiently pure being the source of supply for the country immediately surrounding. There are no reliable records of the size of the ice crop within this basin. The industry is largely localized, each field having a different ownership, and the returns made by the different owners are certainly not correct, for the endeavor to escape taxation has induced the several companies to make returns which are usually far below the actual amount of ice cut. The common measurement of ice in the fields is 1,000 tons to the acre, the ice being about 12 inches thick. Within the Merrimac Basin it is possible to cut two or three crops. According to the Tenth Census report on water power there are about 100 square miles of pondage in this basin, equal to 64,000 acres. Assuming that 25 per cent of this area is available for ice cutting and allowing for only one crop during the season, which is certainly a low average, there would be available

160,000 tons on the lakes alone. Allowing for a large crop on the rivers, it appears that 1,000,000 tons a season is a conservative estimate, and the total amount cut is probably far more than this. At all events, the value of this system as a source of ice supply is very great.

FLOW MEASUREMENTS.

During a series of years the flow of the Merrimac has been carefully measured at Lawrence, and the discharge is given in the following table:

TABLE 5.—*Estimated annual discharge of Merrimac River at Lawrence, Mass.*

[Drainage area, 4,553 square miles.]

Year.	Discharge in second-feet.			Run-off.		
	Maximum.	Minimum.	Mean.	Total in acre-feet.	Depth in inches.	Second-feet per square mile.
1890	31,560	590	9,373	6,785,786	27.93	2.06
1891	39,000	280	8,370	6,033,916	24.84	1.48
1892	24,800	225	5,869	4,264,911	17.58	1.29
1893	44,800	286	4,850	4,726,807	19.47	1.43
1894	27,900	104	5,035	3,645,052	15.03	1.11
1895	65,300	71	5,799	4,196,973	17.25	1.27
1896	82,150	183	7,187	5,203,029	21.40	1.58
1897	41,499	176	8,002	5,800,105	23.90	1.76
1898	36,000	372	8,413	5,092,341	25.05	1.85
1899	38,200	50	6,464	4,672,824	1.42	19.20

On the Sudbury River, tributary to the Concord, measurements of flow have been regularly made since the year 1875, and are set forth in the following table:

TABLE 6.—*Mean flow of Sudbury River in cubic feet per second, 1875–1900.*

[Drainage area, 75.2 square miles.]

Year.	Second-feet	Year.	Second-feet.	Year.	Second-feet.
1875	111	1885	105	1895	134
1876	118	1886	126	1896	119
1877	111	1887	134	1897	114
1878	169	1888	197	1898	153
1879	101	1889	176	1899	113
1880	67	1890	149	1900	126
1881	114	1891	150	Mean	124
1882	100	1892	90		
1883	62	1893	120		
1884	131	1894	89		

CHARACTER OF NORMAL WATER IN THE MERRIMAC BASIN.

The waters of the Merrimac have been studied more carefully, probably, than those of any other river in the world. The Massachusetts State Board of Health, famous for its pioneer work in modern river survey, has determined very closely the character of the water in that part of the drainage area that lies within the State. No work of importance has been done by the State of New Hampshire, but the waters of the Winnepesaukee have been carefully analyzed by the Commonwealth of Massachusetts. The natural conditions in the drainage area are, however, sufficiently uniform to warrant the assumption that the normal characteristics of the headwaters in Massachusetts are representative for the whole area.

Tables 7 and 8, the first consisting of analyses of practically normal surface waters and the second consisting of analyses of normal ground waters, will fairly serve as an index of the character of unpolluted water in the Merrimac Basin. The last column in these tables shows the number of analyses on which the averages stated were based.

TABLE 7.—*Analyses of normal surface waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Turbidity.	Color.[a]	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Number of analyses made.
Sudbury reservoir	.....	2.2	0.175	0.030	0.001	0.054	2.2	36.2	11	52
Framingham reservoir.	Slight to decided	1.9	.170	.022	.001	.037	2.3	36.3	12	12
Ashland reservoir	do	6.8	.223	.012	.001	.047	2.4	37.2	11	(b)
Nagog Pond, Acton	None to slight	.5	.170	.005	.000	.011	2.4	20.9	2	11
Scott reservoir, Fitchburg.	Slight to decided	1.6	.227	.068	.001	.020	1.4	26.1	2	4
Haynes reservoir, Leominster.	do	1.6	.304	.016	.000	.020	1.0	18.7	1	4
Morse reservoir, Leominster.	Very slight to slight.	2.3	.198	.007	.000	.030	1.2	21.0	2	4
Sandy Pond, Concord.	.....	.3	.129	.001	.001	.011	2.5	26.6	....	....
Crystal Lake, Haverhill.	.....	1.3	.166	.009	....	.030	3.0	32.2	....	.....
Lake Winnepesaukee.	.....	1.0	.093	.002	.000	.038	[c]1.2	20.9	....	24
Penacook Lake, New Hampshire.[d]	.....	1.0	.138	.020	.000	.000	1.4	32.0	11	1

[a] Nessler scale.
[b] Over 80, extending over 13 years.
[c] Excess of chlorine, 0.2.
[d] Furnished by H. E. Barnard, New Hampshire State Laboratory of Hygiene.

TABLE 8.—*Analyses of normal ground waters in Merrimac Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Number of analyses made.
El-Hazar, Lowell	2	0.012	0.004	0.000	0.025	1.0	24.0	5	2
Ballardvale, Andover	3	.012	.003	.000	.035	2.4	23.5	4	2
Framingham	1	.025	.000	.000	.065	2.2	38.0	17	2
Pepperell	1	.006	.003	.000	.065	1.5	53.0	24.5	2
Concord	0	.025	.006	.000	.260	2.6	26.5	4	3
Methuen	0	.012	.003	.000	.150	2.0	85.0	21	2
Chelmsford	2	.022	.006	.000	.510	2.8	27.0	6	1
Dracut	2	.077	.008	.000	.040	2.7	33.5	6.5	2
Well in Sandbarton	0	.000	.000	.000	.300	1.76	55.0	2.0	1

POLLUTION IN THE MERRIMAC BASIN.

The country drained by the Merrimac River system contains a population of about 632,560, according to the national census of 1900. Of this number, 414,040 dwell in Massachusetts. The population per square mile within the whole area is therefore 151; that in New Hampshire is 71.4; that in Massachusetts is 364.4. A large proportion of this population is concentrated within cities and large towns, so that the above figures do not, even approximately, represent the actual conditions in the drainage area.

Pollution exists in the basin to an extent that has made the waters a fruitful source of study. On the main river, between Newburyport, Mass., and Concord, N. H., there is a large civic population supplied with sewerage systems, from which large volumes of crude sewage are daily poured. Some of the tributaries also receive a damaging amount of pollution. The latter will first receive attention, and their effects will be gathered together and summed up in connection with the pollution in the Merrimac proper.

SHAWSHEEN RIVER.

Rising in the historic town of Lexington, Mass., the Shawsheen runs in a northerly direction and enters the Merrimac at Lawrence. It is a somewhat unimportant stream from the standpoint of natural resource; the flow is unsteady and the power values poor. As a source of water supply it would furnish in the driest year about 20,000,000 gallons of bad water daily from the 34.1 square miles on the upper end of the drainage basin.

The population of the portion of the area above mentioned is about 125 per square mile, and appears to be growing rapidly. Few precau-

tions have been taken to keep the waste from this number of people out of the river, and the country is highly fertile and swampy to a large degree, so that the water of the river contains an abundance of organic matter and has a high color.

Analyses of the water of the river have been made by the State Board of Health, as follows:

TABLE 9.—*Analyses of water from Shawsheen River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Number of analyses made.
Bedford	Slight	15	0.311	0.000	0.002	0.035	5.9	76.7	22	2
Wilmington	None to distinct.	9.6	.272	.018	.001	.085	3.5	56.3	.	24
Andover	Slight to decided	5.1	.385	.074	.001	.047	4.2	55.7	13	3
North Andover	Slight	8.5	.306	.106	.005	.259	3.6	53.5	13	1

The special report of the State Board of Health of Massachusetts, made in 1895, upon the metropolitan water supply has the following:

It was the general opinion from 1874 to 1887 that the water of the Shawsheen River was of satisfactory quality for the purposes of a public water supply; but the investigations of the State board of health since the latter year have shown that this is not the case. The population upon the watershed (123 per square mile) is not very large, but the headwaters of the stream are in the town of Lexington, within 10 miles of the statehouse, where there is likely to be a large growth in the future, and the territory in and beyond Lexington is used to an increasing extent for market gardening. The watershed also contains many swamps, from which the water acquires a high color and takes up much nitrogenous organic matter.[a]

CONCORD RIVER.

Sudbury and Assabet rivers join at Concord, Mass., to form the Concord, which from this point flows in a northerly direction to join the Merrimac at Lowell. (See fig. 3.) The country drained by the system varies in character, a part being extremely flat meadow land, through which the river winds sluggishly, while the remainder is of the hilly, rolling character common to Massachusetts. The Assabet basin and the upper part of the Sudbury are of the latter character, but the Lower Sudbury and the Concord, from the town of Concord to Billerica, are very flat. Two miles from its junction with the Merrimac there is a fall of 40 feet in the Concord, corresponding to the fall in the Merrimac at Lowell.

[a] Report Massachusetts State Board of Health upon a Metropolitan Water Supply, p. 114.

Pollution in the Concord system has been accurately determined. The Upper Sudbury is set apart as a drainage area for a part of the supply of the Massachusetts metropolitan district, and for years

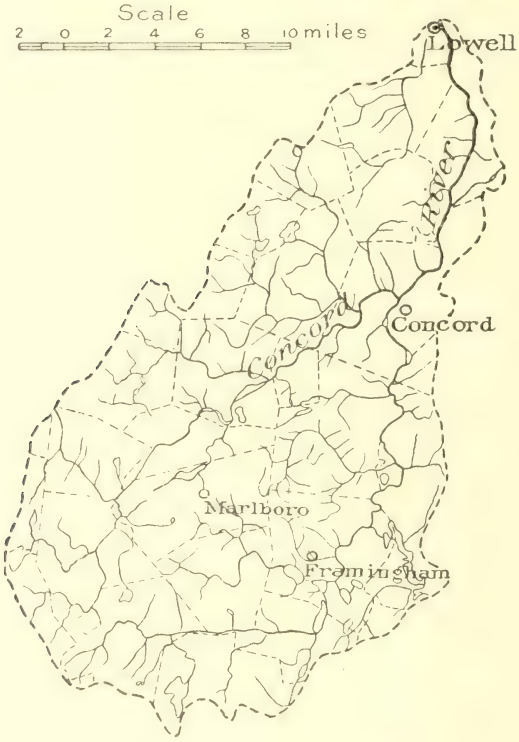

FIG. 3.—Concord River drainage basin.

accurate analyses have been made. The Assabet has been examined with reference to its use as a future source of supply, and the Concord has received attention all along its course.

SUDBURY RIVER.

Drainage area.—In the Sudbury area the city of Boston had six reservoirs built or started, utilizing the water from Farm Pond and Lake Cochituate, when the control was put into the hands of the Metropolitan Water Board. The drainage area here included is as follows:

	Sq. miles.
Reservoirs 1 to 6	74.656
Farm Pond	.543
Lake Cochituate	18.87
Total	94.069

Within this area are Marlboro, Southboro, Westboro, Hopkinton, Ashland, and the largest populated portions of Natick, Framingham,

Sherborn, and Wayland, all representing a population of about 45,300, or 482 per square mile.

Conditions in the area.—That waters can be conserved in so populous an area and delivered in good condition to the citizens of Boston without any purification save that occasioned by storage may be considered remarkable. It is commonly found that a river running out of a valley having so many persons per square mile as live in the basin of the Sudbury is so polluted that its use in the raw state is dangerous. The examination of the condition of the Shawsheen showed what may be expected even in a country with a population of 125 per square mile. It will therefore be profitable to consider the conditions

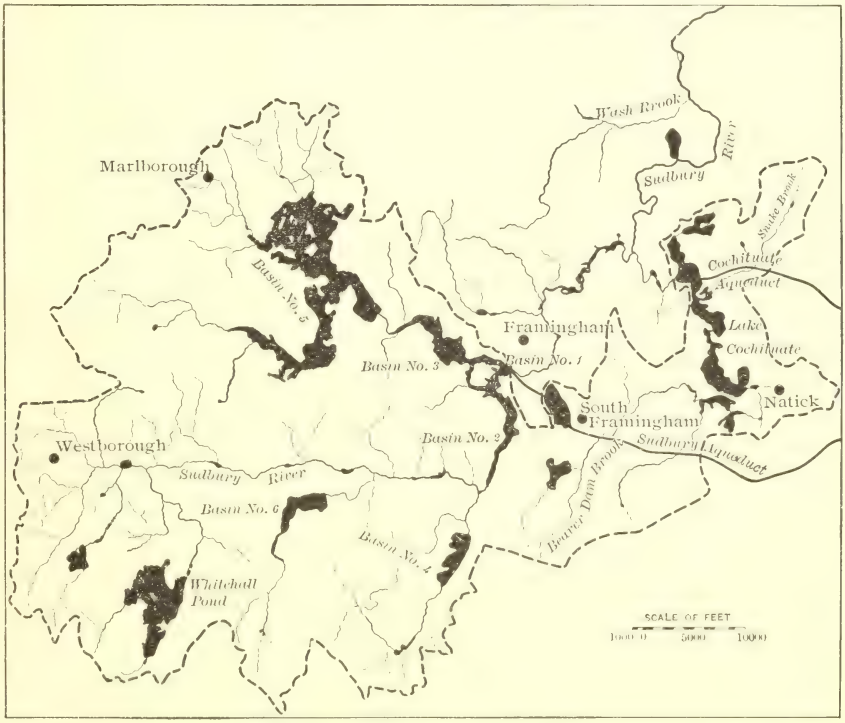

FIG. 4. Sudbury River drainage basin.

within the Sudbury area and show how it is possible to maintain the run-off water in a normal state.

Examination of the accompanying map of the area (see fig. 4) will show that Westboro is situated on the western divide of the Sudbury, and just beyond the divide is the sewage-disposal work for the town. On the northern boundary is Marlboro, a city of importance, and to the east, over the divide, is another disposal works. In the stream known as Walker Brook, running through Marlboro to the great Sudbury reservoir, has been placed a filter, and all of the water from the

city of Marlboro, which, as shown by analysis, is extensively polluted, is purified before being mingled with the pure water in the reservoir. Within the Cochituate Basin are South Framingham and Natick, both with sewerage systems and sewage-disposal works the latter situated outside of the drainage area. In addition to this, a filtration system has been established at the Reformatory Prison for Women, while the water of Pegan Brook, running from Natick into Lake Cochituate, is filtered like that of Walker Brook in Marlboro. The differences between the waters of this area and those of others having an equal population are due entirely to these precautions.

Out of the Sudbury and Cochituate basins there were daily drawn in the year 1902 about 41 million gallons of water. If it were not for the filtration of polluted water described in the foregoing paragraph, the water from this area would be quite unfit for domestic use, and this large investment would diminish in value or would fail completely. It would be necessary to filter the entire output, which would cost at least $5 per 1,000,000 gallons, or, at the present rate of consumption, $74,800 annually. Under the present conditions the expense of sewage purification in the Sudbury and Cochituate basins amounts to a small fraction of this sum annually. Thus by an expenditure of a small amount of money for the construction of disposal works and a comparatively insignificant amount for maintenance the value of the Sudbury resource is preserved. This is a typical case, illustrating what may be done in the way of preserving in its normal state the water of a populous district. It stands forth in contrast to the many cases hereinafter taken up, in which all thought of preservation of values undamaged is thrown to the winds.

Character of water.—The character of the water in the Upper Sudbury Basin is well set forth in the first three analyses in Table 7, page 37. It will be seen that from all evidences the precautions taken are successful, for the waters are practically normal. The Cochituate water is also nearly normal and is similar in many respects to that of the Sudbury, possessing, however, a much lighter color. The color of the Sudbury water has been improved during recent years by the drainage of swamp lands in the watershed.

Passing out of the hilly region, the Sudbury winds along the plain through the towns of Sudbury, Wayland, and Lincoln, carrying along the incidental pollution from these places as well as that from Framingham Center and the effluent from the Natick, Marlboro, and Framingham filter beds. This pollution has its effect upon the river, as is shown by the marked change in the character of the water. The following analyses of waters, taken along the Sudbury, Assabet, and Concord at different points, are reproduced from the report of the Massachusetts State Board of Health for 1900.

TABLE 10.—*Analyses of water from Sudbury River between Saxonville and Wayland (Farm Bridge).*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	No.	Place of collection.
Aug. 15, 1900	Very slight	3.4	0.216	0.040	0.002	0.000	3.6	40.0	16	1	Dam above Saxonville Mills.
Aug. 29, 1900	do	2.2	.244	.012	.000	.030	3.6	40.0	16	2	Do.
Do	Decided	8.0	1.500	.390	.000	.020	9.0	118.0	22	3	3,000 feet below Saxonville dam.
Feb. 27, 1901	do		2.720	5.040	.013	.200	11.1	162.5	27	4	4,000 feet below Saxonville dam.
Aug. 15, 1900	do	6.1	1.000	.110	.007	.010	7.3	90.5	20	5	1 mile below Saxonville dam.
Do	do	6.1	.850	.140	.004	.010	6.9	103.0	22	6	2.7 miles below dam.
Aug. 29, 1900	do	3.3	.600	.300	.004	.020	8.7	92.5	26	7	Do.
Feb. 27, 1901	do	6.0	.940	.940	.070	1.020	16.8	153.0	29	8	Do.
Aug. 29, 1900	Slight	3.0	.336	.136	.000	.020	8.0	69.5	26	9	4.1 miles below dam.
Aug. 15, 1900	do	3.0	.292	.136	.004	.010	6.3	74.5	25	10	6 miles below dam.
Aug. 29, 1900	do	2.9	.376	.032	.003	.010	8.3	80.0	26	11	Do.
Feb. 27, 1901	do	2.7	.206	.172	.018	.420	6.8	71.5	25	12	Do.

TABLE 11.—*Analyses of water from Sudbury River between Wayland and Concord.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	No.	Place of collection.
Aug. 11, 1900	Slight	2.9	0.246	0.072	0.005	0.030	6.6	61.5	22	13	Canal bridge.
Aug. 29, 1900	Very slight	3.6	.258	.046	.002	.020	6.3	62.5	23	14	Do.
Feb. 27, 1901	do	2.9	.214	.244	.010	.410	6.5	64.5	22	15	Do.
Average		3.1	.239	.121	.006	.153	6.5	62.8	22		
Aug. 15, 1900	Very slight	3.0	.260	.022	.004	.000	5.6	56.0	23	16	Lee's bridge.
Aug. 29, 1900	do	2.3	.244	.030	.000	.020	6.8	58.0	20	17	Do.
Average		2.6	.252	.026	.002	.010	6.2	57.0	21		
Aug. 15, 1900	Very slight	3.0	.226	.026	.001	.000	6.0	54.0	20	18	Heath's bridge.
Aug. 29, 1900	do	1.9	.222	.024	.000	.030	5.8	58.5	18	19	Do.
Feb. 27, 1901	Slight	3.6	.250	.142	.006	.380	6.2	71.5	20	20	Do.
Average		2.8	.233	.064	.002	.137	6.0	61.3	19		
Aug. 15, 1900	Very slight	3.0	.262	.044	.002	.000	5.8	55.0	22	21	Near mouth Concord.
Aug. 29, 1900	do	2.2	.222	.034	.000	.010	5.5	59.0	21	22	Do.
Feb. 26, 1901	Slight	3.2	.274	.122	.005	.290	6.0	64.5	21	23	Do.
Feb. 27, 1901	do	3.7	.284	.144	.005	.380	5.9	65.0	21	24	Do.
Average		3.0	.260	.086	.003	.170	5.8	60.9	21		

Findings.—The dates of collection of the samples reported in Tables 10 and 11 are well selected to show the character of the water in Sudbury River in midsummer and midwinter seasons. The analyses given show clearly the effects of pollution on the river along the entire course, from the borders of the restricted area to the mouth of the Assabet, in Concord. Samples 1 and 2, taken from the dam above Saxonville mills, show the effects of contamination from Framingham Center in the content of chlorine. The normal chlorine map shows that the proper amount for this area is about 2.5 parts per million, while that in the samples indicated is 3.6. The amount of nitrogen in the two determinations is noticeably low. This may be due in part to the short term of storage afforded in the mill pond above Saxonville dam, but the more correct explanation is probably that the water which runs out of the restricted area below the reservoirs has little polluting material turned into it, except that of an indirect nature, and the only testimony which remains is the abnormal amount of chlorine. As far as the analyses show, the water from above Saxonville dam may be taken to represent roughly the character of the unpolluted Sudbury water. A comparison with the analyses of the water taken from points below may be fairly made upon this basis. Nos. 3 and 4 show clearly the effects of pollution from Saxonville, while 5, 6, 7, and 8 well represent the effects of oxidation, sedimentation, and dilution with fairly pure water from small tributaries. No. 8 shows in an instructive way the difference in the purifying action of those three agents during the cold season. Nos. 9–12 in Table 10 and 13–24 in Table 11 present no remarkable features, and merely indicate the continued effects of self-purification in a river which runs through a district sparsely populated. It is interesting to note that the amount of chlorine remains high, increasing as the points of pollution are passed, and thereafter being reduced in proportion to the dilution from tributary streams.

ASSABET RIVER.

The drainage area of this river is a narrow one, lying between the drainage basin of the Sudbury and that of the Nashua. The country is fertile and the affluent from sewage-disposal works at Westboro and the pollution at the village of Northboro all assist in contaminating the stream. The special report of the State Board of Health in 1895, in considering future sources of supply for the metropolitan district, contains the following statement:

> Owing to the polluting matters which enter the streams at Northboro, to the very large area of swampy land along the river between Northboro and the Boston and Albany Railroad, and to the disposal of the sewage of Westboro upon the banks of this section of the river (Assabet), it is not of suitable quality for water-supply purposes.

The analyses published at that time fully bore out this statement,

but since then the river has become more polluted. The annual report of the State board for the year 1900 contains the following analyses:

TABLE 12.—*Analyses of water from Assabet River.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as Albuminoid ammonia.	Nitrogen as Free ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	Total residue.	Hardness.	Place of collection.
Feb. 27, 1901	Decided	5.0	0.520	0.204	0.002	0.280	4.3	60.0	16	2 miles above Northboro.
Aug. 15, 1900	Slight	5.4	.392	.100	.003	.000	5.2	53.0	18	Below Hudson.
Aug. 29, 1900	Decided	7.0	.110	.640	.001	.020	24.9	124.5	23	Do.
Feb. 27, 1901	do	3.3	.416	.256	.005	.300	15.9	80.5	18	Do.
Do	do	4.0	.336	.188	.005	.230	7.1	66.0	14	Below Gleasondale.
Aug. 15, 1900	do	3.0	.376	.140	.002	.000	6.7	53.5	11	Below Maynard.
Aug. 29, 1900	do	3.4	.425	.090	.003	.010	7.6	61.5	11	Do.
Feb. 27, 1901	do	3.5	.480	.288	.004	.200	7.1	70.5	16	Do.
Aug. 15, 1900	Slight	3.2	.388	.216	.007	.070	6.5	50.5	13	Near mouth.
Aug. 29, 1900	Very slight	2.4	.278	.138	.005	.040	7.8	57.5	13	Do.
Feb. 26, 1901	Slight	3.5	.308	.164	.004	.260	6.6	57.0	18	Do.
Feb. 27, 1901	do	3.5	.296	.230	.005	.280	5.9	63.0	16	Do.

CONCORD RIVER, BETWEEN CONCORD AND LOWELL.

Below Concord, the river slowly winds through a country of scanty population, without materially adding to the pollution which it bears along. The water perceptibly improves through the same agencies as are above noted in the case of the Sudbury, until it comes within the polluting influence of Lowell.

TABLE 13.—*Analyses of water taken at different points along Concord River.*

[Parts per million.]

Turbidity.	Color.	Ammonia. Albuminoid.	Ammonia. Free.	Nitrogen as— Nitrites.	Nitrogen as— Nitrates.	Chlorine.	Total residue.	Hardness.	Place of collection.
Very slight	3.2	0.286	0.102	0.004	0.030	6.4	53.5	16	Below North Bridge, in Concord.
Do	3.0	.250	.080	.003	.040	6.7	55.0	15	At Flint's bridge, in Concord.
Slight	3.4	.278	.158	.005	.330	6.3	63.5	15	Junction Sudbury and Assabet.
Very slight	11.0	.352	.030	.002	.130	5.2	59.0	16	Billerica.
Do	2.6	.224	.044	.001	.010	9.4	61.0	25	Above Billerica water works.
Do	2.0	.222	.040	.000	.010	5.9	54.0	14	North Billerica.
Do	2.0	.220	.018	.000	.010	5.9	52.0	14	Above Talbot's mill, Billerica.

NASHUA RIVER.

Nashua River rises in Worcester County, Mass., and flows in a northeasterly direction into New Hampshire, where it joins the Merrimac at Nashua. Above Lancaster, Mass., the river divides into the North and South branches, the former coming down from the northwest, the latter having traced a circuitous course in a general northeasterly direction. (See fig. 5.)

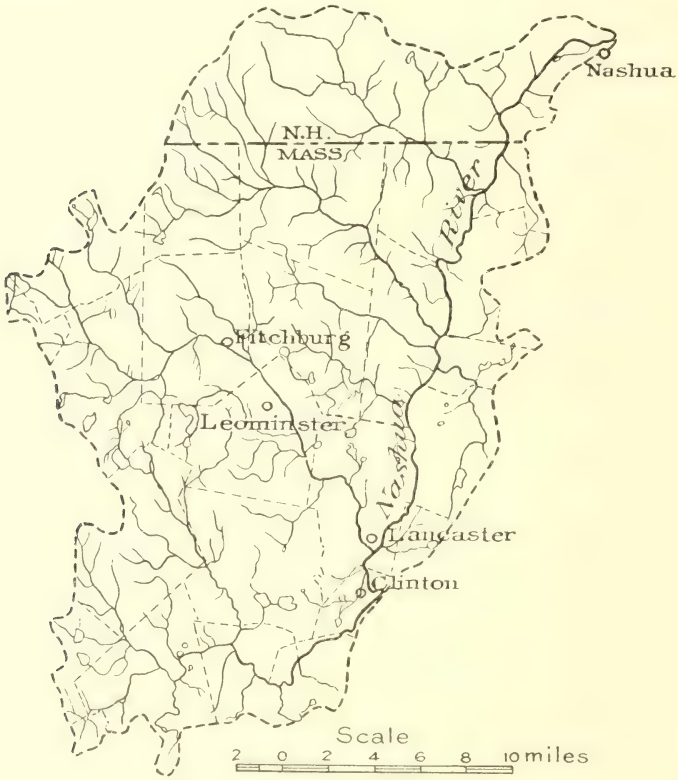

FIG. 5. Nashua River drainage basin.

There are situated within the Nashua Basin 23 municipalities, exclusive of Nashua, at the mouth, some of which extend over across the divide into other watersheds. The total population, according to the Twelfth Census, is about 83,200, or neary 161 per square mile. This, however, does not fairly represent the conditions upon the river system, for upon many branches the country is sparsely settled. Large settlements are not numerous, and only three are of important size. Fitchburg, on the North Branch, has a population of 31,531; Leominster, a short distance below, is reported to have 12,393; and Clinton, the only important center on the South Branch, has 10,251 inhabitants.

SOUTH BRANCH OF NASHUA RIVER.

The South Branch of the Nashua has a drainage area of 129 square miles, the topography being hilly and steep, affording admirable opportunities for storage. The upland branches, Quinepoxet and Stillwater, join to form the South Branch, bringing in the waters of a country of small population and affording a supply of excellent quality. Practically all of this upland area has been set aside by the Metropolitan Water Board for the conservation of a supply for Boston and vicinity. The river is intercepted by a mammoth dam, which will hold back the waters of one of the largest reservoirs ever constructed, at a point just above Clinton.

The waters of the reservoir will cover the present villages of Boyleston, West Boyleston, and Harrisville, and the work of effacing these places has already been carried forward. At the time of the first report on the project, in the year 1895, the population of the proposed restricted area of 118.23 miles was 61 per square mile. Since that time there has been practically no increase over the whole country, and recently the destruction of the villages above mentioned has caused a marked decrease. The completion of this work will effect a change in the quality of the water taken from this basin. The few points of pollution now existing there will be removed and storage in the new reservoir will improve the character of the water. Yet even now the supply which is taken from the river and carried through the aqueduct constructed across the eastern watershed to the Sudbury Basin is of excellent quality and will serve as a normal from which to consider the pollution in the lower reaches of the river. Reference to the map of normal chlorine, page 28, will show that the proportion for this country is 1.6 parts per million.

Quinepoxet and Stillwater rivers.—From the Massachusetts reports have been taken the following statements of analyses of waters gathered from the Quinepoxet and Stillwater rivers, the one at Holden and the other at Sterling:

TABLE 14.—*Analyses of water from Quinepoxet and Stillwater rivers.*

QUINEPOXET RIVER AT HOLDEN.

[Parts per million. Averages by years.]

Year.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1892	Slight	6.2	0.194	0.014	0.001	0.088	1.9	37.0	9
1893	do	7.2	.192	.004	.001	.044	2.6	37.5	9
1894	do	6.1	.214	.041	.001	.027	2.9	38.5	7
1895	Very slight to distinct.	7.7	.289	.020	.003	.090	2.6	44.7	9
1896	do	6.4	.250	.012	.000	.045	1.9	37.4	4
1897	Very slight to decided.	7.7	.275	.032	.001	.055	2.1	38.8	8
1898	Slight	6.2	.248	.030	.001	.037	2.1	34.7	8
1899	Very slight to decided.	4.8	.261	.028	.001	.046	1.9	36.5	5
1900	do	5.1	.277	.036	.002	.047	2.1	38.8	5
STILLWATER RIVER AT STERLING.									
1892	None to slight	4.4	0.131	0.001	0.000	0.072	1.3	33.8	9
1893	do	5.0	.147	.006	.001	.002	1.8	34.5	7
1894	do	4.5	.137	.008	.000	.017	1.8	32.0	8
1895	do	5.2	.179	.008	.000	.051	1.9	34.8	9
1896	Very slight to distinct.	5.0	.229	.016	.000	.035	1.6	33.2	7
1897	None to very slight.	6.6	.199	.013	.000	.037	1.7	34.7	8
1898	do	5.1	.158	.008	.001	.026	1.6	30.2	8
1899	Very slight	3.1	.177	.020	.000	.050	1.7	32.4	5
1900	None to very slight.	3.3	.156	.025	.001	.025	1.5	30.7	7

South Branch of Nashua River at Clinton.—Just below the dam which marks the beginning of the restricted area above described the South Branch passes the town of Clinton, and there meets with its first important pollution. Flowing through Clinton from the west, Coachlace Brook enters the main stream. The large plant of the Lancaster Woolen Company, employing over 2,000 hands, contributes sewage and manufacturing refuse into the South Branch, and a small portion of the town also drains into this stream. Until September 15, 1899, the sewage of Clinton and an enormous quantity of wool-washing waste and other refuse from the extensive works of the Bigelow Carpet Company were discharged into Coachlace Brook.

In Table 15 is set forth results of four analyses of water from Coachlace Brook, which was at that time the foulest stream in the Nashua Basin.

TABLE 15.—*Analyses of water from Coachlace Brook.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Slight	3.5	0.620	2.280	0.056	0.180	10.0	96.5
Do	2.3	.520	2.200	.033	.330	9.5	89.0
Distinct	2.0	.710	1.720	.044	.200	9.9	94.5
Decided	4.0	.786	1.620	.200	.050	9.7	110.0
Average	2.9	.659	1.955	.083	.190	9.8	97.5

Character of water at Lancaster.—A short distance below this point is Lancaster, the place at which the North Branch enters. The quality of the water has been determined by a long series of analyses of samples taken at a point on the South Branch just above the confluence of the two rivers. The place was well chosen, for the water taken there shows the effect of the mixture of the water from Coachlace Brook and that running past the Lancaster mills, as above described.

TABLE 16.—*Analyses of water from South Branch of Nashua River above its confluence with North Branch at Lancaster.*

[Parts per million.]

Year.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1895	Very slight to distinct.	5.3	0.238	0.167	0.008	0.114	3.4	46.6	14	16
1896	Distinct	4.5	.216	.094	.006	.134	3.5	47.2	16	12
1897	Very slight to distinct.	6.0	.257	.092	.004	.110	3.2	44.7	13	12
1898	Very slight to decided.	5.0	.269	.327	.010	.098	3.3	47.7	13	12
1899	Very slight to distinct.	4.5	.415	1.026	.018	.087	7.5	73.4	17	12
1900	Very slight to decided.	3.3	.346	.537	.020	.392	10.0	77.3	19	12
1901	Decided	3.3	.331	.314	.012	.405	8.1	78.4	19	12

NORTH BRANCH OF NASHUA RIVER.

The North Branch of the Nashua is a good power stream and has been utilized extensively. Its flow is regulated to some extent by a series of reservoirs, but in spite of this the flow is variable. The total area of the basin is 127 miles, and the population is greater than that on the South Branch. The communities of Leominster and Fitchburg contain 44,000 inhabitants; both places support extensive manufacturing industries, and the pollution from household sewage and factory wastes is extensive. There are, nevertheless, many points in the watershed above these towns where the water is of excellent quality. Among these are Scott reservoir, which supplies Fitchburg, and Morse and Haynes reservoirs above Leominster, analyses of which are recorded in Table 7.

Normal water.—Still farther up in the drainage area is the Ashburnham storage reservoir, which conserves a normal water of a character indicated in the following report of analysis, it being the average of nine samples:

TABLE 17.—*Analysis of water from Ashburnham storage reservoir.*

[Parts per million.]

Turbidity	"None" to "distinct."
Color	None.
Residue on evaporation	25.2
Free ammonia	.003
Albuminoid ammonia	.077
Chlorine	[a]1.3
Nitrates	.191
Nitrites	.001

Above Fitchburg.—Taking the waters of Scott, Haynes, Morse, and Ashburnham reservoirs as normal, let us descend to a point a short distance above Fitchburg, where the pollution is merely that from a few factories in the vicinity of West Fitchburg.

TABLE 18.—*Analyses of water from North Branch of Nashua River above Fitchburg.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as Albuminoid ammonia.	Nitrogen as Free ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	Total residue.	Hardness.
1900.									
June 19	Very slight	3.8	0.170	0.002	0.001	0.050	1.4	33.5	5
August 1	do	4.5	.182	.008	.000	.010	1.6	32.5	5
August 29	None	3.9	.170	.010	.000	.050	1.8	31.5	5
September 26	Slight	3.8	.216	.008	.001	.030	2.3	26.5	5
October 23	None	4.2	.192	.012	.000	.020	2.3	42.5	8
November 28	do	6.0	.178	.022	.000	.070	1.8	35.0	10
December 26	Very slight	4.5	.130	.012	.001	.130	1.8	36.0	8
Average		4.4	.177	.011	.000	.051	1.9	33.9	7

[a] None.

Except for a slight increase in the amount of chlorine the above analyses do not differ significantly from those in the normal reservoirs above noted. This difference is, however, an important one and bears unmistakable evidence of the pollution above noted.

Below Fitchburg.—Below Fitchburg the character of the water undergoes a marked change, as is indicated by the following series of analyses of samples taken at a point just below the city. It will be observed that, although the evidences of pollution are clear, they do not indicate the extremely foul character which was apparent in the waters of Coachlace Brook, on the South Branch.

TABLE 19.—*Analyses of water from North Branch of Nashua River below Fitchburg.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1893	5.7	0.360	0.461	0.018	0.118	6.9	74.6	20
1894	5.6	.346	.634	.020	.152	7.5	73.9	19
1895	5.9	.423	.832	.010	.134	7.5	81.0	22
1896	4.8	.499	.677	.017	.151	7.4	81.5	20
1897	6.1	.420	.370	.007	.120	6.1	68.2	18
1898	5.1	.467	.435	.009	.117	4.8	60.0	16
1899	4.3	.657	.967	.009	.069	7.2	76.2	18
1900	3.9	.660	1.011	.010	.072	9.7	81.0	20

Below Leominster.—Descending farther we come to Leominster, at which place enters a polluted stream known as Monoosnoc Brook, the characters of which are shown by the following statement, which is the average of ten analyses made in 1899 and 1900.

TABLE 20.—*Average of ten analyses of water from Monoosnoc Brook.*

[Parts per million.]

Turbidity	Decided.
Color	7.5
Residue on evaporation	49.9
Free ammonia	.280
Albuminoid ammonia	.444
Chlorine	4.3
Nitrates	.071
Nitrites	.0075
Hardness	12

At Lancaster.—Another series of analyses appears to have been made, the water being taken from the North Branch at a point just above its confluence with the South Branch. This point is also well chosen, as the river carries all the pollution which has entered above save that which has been oxidized or deposited in the course of the stream. Analyses of the water here show just what is contributed by the North Branch to the Nashua River system.

The following record covers six years, and can therefore be accepted as indicative of the true character of the water:

TABLE 21.—*Analyses of water from North Branch of Nashua River, just above its confluence with the South Branch at Lancaster.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	5.1	0.269	0.282	0.019	0.236	7.7	69.6	19
1896	4.7	.293	.217	.019	.155	5.5	61.6	18
1897	5.4	.290	.285	.008	.150	4.2	52.9	15
1898	4.5	.268	.222	.013	.168	4.4	50.7	15
1899	3.6	.316	.540	.016	.132	6.0	63.8	16
1900	3.1	.322	.501	.022	.152	6.6	63.4	18

A comparison of the results in Table 21 with the analyses of water from the South Branch, Table 16, shows that until 1899 North Branch was the more highly polluted.

During the years 1895–1898, inclusive, the amounts of free ammonia, nitrates, and chlorine in South Branch water were approximately 50 per cent of those in North Branch. After 1898 there appears to be a decided change in the character of the water in South Branch; organic ingredients increased remarkably and reached a maximum in the year 1900. It is evident that unusual conditions arose to produce this result. A history of the work of the Metropolitan Water Board of Massachusetts upon the South Branch of Nashua River shows that in March, 1898, a large proportion of the run-off water in the basin of South Branch above Clinton was diverted for use in the metropolitan district. This water had, up to this time, been efficient in diluting the refuse and sewage discharged from Clinton, and its withdrawal was immediately apparent in the condition of the stream below. Coincident with this diversion there was in progress the preparation of Wachusett reservoir; old dams were removed, the surface of the country was stripped of vegetation, and large amounts of water were

turned into the stream from foundation-wall excavations. The result was that the water which flowed past Clinton was made extremely turbid, and must have carried along in solution, as well as in suspension, great quantities of organic matter. These conditions are entirely sufficient to account for the change in the character of South Branch water above its confluence with North Branch.

The unfavorable change in the character of the water in South Branch is only temporary. The beginning of an improvement took place late in the fall of the year 1899, when the sewage of Clinton and the manufacturing wastes of the Bigelow Carpet Company were diverted into newly constructed purification works. The completion of Wachusett reservoir will mark the end of the operations which have increased the organic constituents in the river water and South Branch will be restored to its former condition, or be greatly improved. Mr. F. P. Stearns, chief engineer of the Metropolitan Sewerage and Water Board, has expressed the belief that the above result will be reached in the fall of the year 1903, or early in the spring of 1904.

From Lancaster to Nashua, N. H.—We have now traced the pollution in the headwaters of the Nashua branches down to a point at which the main river takes its origin. From this point to Groton the river flows very sluggishly, and from Groton to a point 3 miles from its confluence with the Merrimac its fall is more rapid, becoming quite steep for the remainder of the course. From Lancaster to Nashua there is no settlement contributing important pollution. As the river sluggishly winds along its course it is increased in flow by other streams, notably the Squannacook at Ayer and the Nissitisset at Pepperell, so that when it reaches the latter place dilution, sedimentation, and oxidation have had an effect which may be readily seen by examining the following reports of analyses:

TABLE 22.—*Analyses of water from Nashua River at Groton and Pepperell.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Place of collection.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
May 22, 1895	Decided	4.0	0.164	0.014	0.003	0.170	4.0	48.5	16	Groton.
Aug. 16, 1899	Slight	2.0	.264	.116	.014	.230	7.0	65.0	17	Pepperell.
Sept. 21, 1899	Very slight	2.7	.230	.054	.012	.150	8.2	67.5	20	Do.
Oct. 14, 1899	do	2.4	.236	.168	.004	.060	9.7	75.5	23	Do.
Mar. 15, 1899	Decided	4.2	.264	.332	.003	.110	6.4	68.5	23	Do.
July 16, 1900	Very slight	1.5	.200	.100	.005	.050	7.0	60.0	20	Do.
Aug. 21, 1900	Slight	2.3	.258	.234	.018	.100	9.2	65.0	20	Do.

Flowing ever more swiftly it passes into the State of New Hampshire and emerges at Nashua in the Merrimac. The average of 19 analyses made during the years 1887–88 appear below. The samples were taken at Mine Falls, above Nashua pollution.

TABLE 23.—*Average of nineteen analyses of water from Nashua River at Mine Falls.*

[Parts per million.]

Turbidity	Slight to decided.
Color	3.8
Residue on evaporation	45.8
Free ammonia	.029
Albuminoid ammonia	.187
Chlorine	[a] 2.9
Nitrates	.102
Nitrites	.003

OTHER TRIBUTARIES OF THE MERRIMAC.

Outside of the State of Massachusetts the character of the waters of the Merrimac drainage area is almost unknown. The New Hampshire laboratory of hygiene has not yet been established for a time sufficient to allow extensive investigations. It is probable that in due time this laboratory will complete the work which has been carried on by the State Board of Health of Massachusetts.

Piscataquog and Contoocook rivers.—No analyses are available of the water of the Piscataquog or Contoocook. It is safe to assert that neither stream is polluted to any extent, for there are no important settlements in the valleys. The population in the basin of the Contoocook is only 31.4 per square mile.

Lake Winnepesaukee.—The water of Lake Winnepesaukee has been analyzed by the Massachusetts State Board of Health for the purpose of determining its fitness as a source of supply for the metropolitan district. The average is included in Table 7.

Pemigewasset River.—The Pemigewasset Valley, which lies at the head of the Merrimac system, has a population of 17 per square mile. No sewerage systems enter the river, nor are there any large centers of population. The supply of water to the Merrimac is therefore pure and abundant. The only available analysis has been kindly furnished by Mr. H. E. Barnard, chemist of the New Hampshire laboratory of hygiene. The place of collection was at Campton Village, at the extreme southern end of the basin. It therefore fairly represents the character of the water furnished by the Pemigewasset drainage area to the Merrimac.

[a] Chlorine 1.4 above normal.

TABLE 24.—*Analysis of water from Pemigewasset River at Campton, N. H.*

[Parts per million.]

Appearance.			Ammonia.				Chlorine.	Nitrogen as—		Hardness.
				Albuminoid.						
Turbidity.	Color.	Total residue on evaporation.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
None	4.0	34	0.016	0.094			0.637	0.100	0.100	...

POLLUTION OF MERRIMAC RIVER AT MANCHESTER, NASHUA, LOWELL, LAWRENCE, AND HAVERHILL.

Having considered the characteristics of the water in the tributaries which have received attention from analyses, let us review the work which has been done in the Merrimac proper and show, as closely as possible with the data at hand, how each tributary affects the river; also the changes due to the extensive pollution which arises from the cities along the bank.

Manchester.—We have said that the upper part of the Merrimac area is sparsely settled, and that such analyses as are available show that the water is pure. From the Contotook, Pemigewasset, and Winnepesaukee drainage basins there is delivered into the Merrimac a great volume of water, which is increased by the numerous smaller tributaries which enter all along the course. It is not likely that it changes greatly in character until it reaches Manchester, N. H., an important manufacturing city of 56,987 inhabitants. Sewage and manufacturing wastes are poured directly into the river, and, although there are at hand no analyses to show the exact condition of the water, it is certain that the change is marked.

Nashua.—Sixteen miles below, at the city of Nashua, a series of analyses has been furnished by Mr. Barnard which shows the effect of Manchester pollution after it has been carried along for the above distance. It is at this point that the abundant flow of Nashua River enters the Merrimac, dilutes still further the Manchester pollution, and renders the sewage from Nashua, a city of 23,898 inhabitants, less damaging than it would be under conditions not so favorable.

TABLE 25.—*Average of nineteen analyses of water from Merrimac River at Nashua.*

[Parts per million.]

Appearance.			Ammonia.				Chlorine.	Nitrogen as		Hardness.
				Albuminoid.						
Turbidity.	Color.	Total residue on evaporation.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.	
Slight	3.4	50.1	0.014	0.153	...	...	1.5	0.074	0.002	6.0

Lowell.—Leaving Nashua, the river crosses the State line, and when it reaches a point opposite the old water intake at Lowell it is of a quality shown in the following analysis:

TABLE 26.—*Analyses of water from Merrimac River above Lowell.*

[Averages by years, monthly samples. Parts per million.]

Years.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.148	0.016	0.002	0.099	1.6	34.2	--
1889	2.8	.149	.018	.002	.071	1.4	29.5	--
1890	3.0	.128	.014	.001	.111	1.3	35.7	14
1891	2.9	.129	.017	.001	.137	1.3	34.3	12
1892	3.9	.141	.021	.001	.092	1.4	36.1	13
1893	3.3	.149	.026	.001	.082	1.0	33.9	11
1894	3.5	.135	.024	.001	.063	1.8	35.5	11
1895	4.1	.187	.029	.001	.066	2.1	38.4	12
1896	4.0	.167	.024	.001	.070	1.7	34.7	10
1897	5.1	.177	.030	.001	.067	1.5	35.4	10
1898	4.2	.173	.026	.001	.048	1.7	35.3	10
1899	2.7	.287	.050	.002	.060	1.8	36.0	9
1900	2.7	.297	.052	.002	.047	1.9	35.5	11

The water represented in the series of analyses above set forth was formerly used in its raw state as the principal water supply for the city of Lowell. The history of that municipality during this period furnishes to the world one of the clearest illustrations of the cost of water pollution extant, and it stands among epidemiologists as one of the classical examples of disease production through polluted water supply. No history of typhoid fever is complete without an account of the Lowell epidemic. For years the typhoid rate was abnormal, but little attention was given to it until the year 1890, when there occurred from September of that year to January, 1891, a series of 550 cases. Prof. William T. Sedgwick, in a remarkable investigation, traced the origin of the epidemic to a few individuals who, while in the prodromal stage of typhoid fever, had polluted a small brook which enters the Merrimac a short distance above Lowell.

The pecuniary damage caused by polluted water throughout all the years in which the Merrimac was used as a source of supply will never be even approximately estimated. In the epidemic of 1890 alone there was a loss of 92 lives. In addition to this there was the expense incident to the care of 550 cases of the disease and the temporary loss of productiveness of all those who escaped death. The greater part

of this drain upon the resources of the community was without a shade of justification; it might have been prevented by the exercise of municipal decency. After the lesson had been learned, the city of Lowell was obliged to add to the total expense by constructing a new supply, the cost of which will be borne by generations yet unborn.

As the Merrimac passes by Lowell its burden of sewage is increased by the addition of wastes from 95,000 persons and from enormous mills and factories.

Lawrence.—Flowing 9 miles farther the river reaches the city of Lawrence, and there, opposite the intake of the works, the water has a character denoted by the following series of annual averages, each average being the result of monthly analyses:

TABLE 27.—*Analyses of water from Merrimac River above Lawrence.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	3.0	0.180	0.026	0.002	0.094	1.8	36.8	--
1889	3.0	.176	.030	.003	.072	1.7	30.9	--
1890	3.3	.166	.046	.001	.089	1.7	31.9	16
1891	2.7	.152	.040	.001	.110	1.8	37.9	13
1892	4.3	.181	.042	.001	.105	1.8	41.2	14
1893	4.2	.181	.057	.002	.081	2.0	38.6	11
1894	3.7	.167	.062	.001	.063	2.3	37.0	12
1895	5.1	.249	.064	.002	.071	2.8	43.4	14
1896	4.2	.220	.068	.003	.087	2.4	39.8	12
1897	5.6	.228	.049	.001	.067	2.0	38.4	11
1898	4.5	.212	.050	.003	.058	2.2	39.0	11
1899	2.9	.232	.088	.003	.056	2.4	39.9	10
1900	3.0	.224	.089	.002	.060	2.5	39.6	11

The history of the Lawrence water supply and the consequences of its use closely resemble those already described at Lowell, and, indeed, the account of the events in the two cities is generally combined. For years the raw water from the Merrimac was pumped into the Lawrence mains. Following the discharge of typhoid-infected stools from the sewers at Lowell there arose a widespread epidemic in the lower city. In Lawrence the source of supply was not changed, but the first sand filter in the country was established at a cost of $65,000. Through this filter the water of Lawrence is now drawn at an annual expense of $8,000 or $9,000, the result being that the typhoid-fever rate in the city has been considerably lowered.

A comparison of the water after it has been passed through this filter with that in the river is instructive. For this purpose the following analyses are presented, each being the average of 12 monthly samples:

TABLE 28.—*Analyses of the effluent of the Lawrence filter.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	3.9	0.094	0.103	0.002	0.309	3.0	61.0	28
1895	5.0	.108	.146	.001	.274	3.1	59.5	27
1896	4.0	.099	.121	.004	.319	2.5	54.3	24
1897	5.6	.108	.123	.002	.317	2.5	51.7	20
1898	4.3	.090	.107	.001	.324	2.6	46.6	19
1899	2.7	.089	.087	.001	.205	2.8	44.4	16
1900	2.8	.108	.123	.001	.173	2.7	43.0	15

TABLE 29.—*Increase in amount of impurities in Merrimac River water from a point above Lowell to Lawrence, as determined by regular monthly examinations in different years.*

[Parts per million.]

Year.	Color.	Nitrogen as				Chlorine.	Total residue	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1887–1889	0.1	0.027	0.007	0.000	[a]0.003	0.026	2.3	--
1890	.5	.023	.016	.000	[a].020	.280	6.2	2
1891	[a].2	.023	.021	.000	[a].030	.350	2.9	1
1892	.6	.027	.019	.000	[a].013	.390	4.8	0
1893	.9	.032	.031	.001	[a].002	.350	4.7	0
1894	.2	.032	.028	.000	.000	.490	1.5	1
1895	1.1	.063	.022	.001	.005	.630	5.2	1
1896	.2	.053	.034	.002	.017	.700	5.1	2
1897	.6	.051	.019	.000	.000	.500	3.0	1
1898	.3	.039	.024	.002	.010	.440	3.7	1
1899	.2	.045	.038	.001	[a].004	.590	3.9	1
1900	.3	.027	.037	.000	.011	.550	4.1	0

[a] Decrease.

At Lawrence the sewage from 63,000 persons and extensive manufacturing wastes are poured into the Merrimac. Thence the river flows 8 miles to Haverhill.

Haverhill.—Above Haverhill there were, from July to November, 1900, five samples taken, the reports of analyses being as follows:

TABLE 30.—*Analyses of Merrimac River water above Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.3	0.288	0.192	0.004	0.010	3.9	46.5	13
Aug. 21	Decided	1.5	.316	.144	.008	.050	3.9	44.0	16
Sept. 18	Slight	1.5	.328	.272	.009	.020	4.8	50.0	13
Oct. 30	do	3.4	.360	.296	.010	.100	4.4	53.5	14
Nov. 20	Decided	6.5	.328	.144	.003	.080	3.3	53.0	16
Average		3.0	.324	.210	.007	.052	4.1	49.4	14

Haverhill sewage is discharged into the Merrimac. This city has a population of 31,175. Analyses of the water from the river, collected a short distance below the city, are reported by the State Board of Health as follows:

TABLE 31.—*Analyses of Merrimac River water below Haverhill.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	2.0	0.324	0.284	0.007	0.010	4.2	44.0	14
Aug. 21	Decided	1.5	.276	.220	.010	.020	3.7	45.0	17
Sept. 18	Slight	2.3	.375	.265	.017	.040	5.7	55.0	16
Oct. 13	Decided	3.5	.360	.264	.011	.090	4.4	54.0	11
Nov. 20	do	6.6	.340	.136	.004	.120	3.2	53.5	14
Average		3.2	.335	.311	.010	.050	4.2	50.3	12

BLACKSTONE RIVER.

COURSE, CHARACTER, AND UTILIZATION OF THE STREAM.

Blackstone River is a small stream which rises in Worcester County, Mass., and flows in a southeasterly direction, passing over the State line into Rhode Island and emptying into the Providence River at Providence. Its drainage area covers about 458 square miles. At the source the elevation is 438 feet above mean tide and as its course is about 43 miles long its fall must be somewhat more than 10 feet per mile. It is obvious that such a river, so accessible, and in the midst of a populous country, must have unusual value as a source of power. This fact has long been recognized and the stream has been thus utilized, the natural facilities being enhanced by the development of every accompaniment known to be of use in a river of this character. Probably no stream in the United States has been so effectively harnessed and brought into subjugation; milldams have been erected at favorable points, compensating reservoirs have been constructed, and ponds and lakes have been raised in order that the flow may be regulated to meet the demands of manufacturing. The result is that though the river is derived from a watershed which has been extensively deforested, and, under ordinary circumstances it would be subject to floods and variation in flow, its water is seldom allowed to fall below a certain minimum because of the judicious management of the conserved water during dry seasons. The great resource of this stream is, therefore, its water power, and it has been said with authority that the value of this interest is proportionately greater than that found in any other stream in the United States.

POPULATION OF THE BASIN.

Population.—The Blackstone River (see fig. 6) is formed by the junction of Kettle and Mill brooks in the southern part of the city of Worcester. These two brooks drain small parts of the towns of Holden and Leicester, as well as Worcester. The other Massachusetts towns in the basin are Auburn, Millbury, part of Shrewsbury, Grafton, Upton, Sutton, Northbridge, Hopedale, Mendon, Douglass, Uxbridge, and Blackstone, representing a population of about 157,000, or 604 per square mile. In the State of Rhode Island the river drains the municipalities of North Smithfield, Burrillville, Gloucester, Woonsocket, Lincoln, and Cumberland, having a combined population of 56,267.

This large population is mostly in the northern part of the drainage area, at Worcester, Mass., which has a population of 118,421. The population per square mile therefore decreases as the mouth of the river is approached. This fact was well expressed in the report of the Massachusetts Board of Health in 1890, as follows:

TABLE 32.—*Population in drainage basin of Blackstone River.*

	Locality.	Distance below discharge of Worcester sewage.	Drainage area (square miles.)	Population, estimated (1888).	Population per square mile.
		Miles.			
1	At the Quinsigamond Iron and Wire Works	0	63.0	.....	.....
2	At the first bridge below Quinsigamond village	1	63.9	77,500	1,213
3	At the dam of the Cordis Co., Millbury	5	77.9	.....	.....
4	At the upper dam of the Calumet Woolen Co., Uxbridge	17	145.9	90,900	623
5	At the Middleville dam, Blackstone	24	258.1	102,800	398
6	At the dam of the Blackstone Manufacturing Co., Blackstone	26	260.3	.....	.....

Since the collection of the facts in the table the city of Worcester has grown faster than the lower towns in the valley, making the conditions above set forth even more extreme.

FIG. 6.—Blackstone River drainage basin.

NORMAL WATER IN THE BASIN OF THE BLACKSTONE.

Normal water in the basin of the Blackstone has been found at the head of Kettle Brook, Paxton, Lynde Brook storage reservoir in Leicester, and Tatnuck Brook storage reservoir in Holden.

TABLE 33.—*Analyses of normal water in Blackstone Basin.*

LYNDE BROOK STORAGE RESERVOIR.

[Parts per million, averages by years.]

Year.	Color.	Nitrogen as Albuminoid ammonia.	Nitrogen as Free ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	Total residue.	Hardness.
1888	2.4	0.151	0.037	0.001	0.065	1.4	26.4	....
1889	2.4	.167	.030	.001	.053	1.5	25.4	..
1890	2.1	.132	.026	.001	.078	1.4	30.7	9
1891	2.4	.126	.045	.001	.074	1.2	28.3	7
1892	2.5	.139	.038	.000	.105	1.5	29.9	8
1893	2.6	.162	.036	.001	.066	1.5	26.6	6
1894	3.6	.139	.055	.000	.103	1.8	33.7	12
1895	3.2	.161	.033	.000	.116	2.0	36.3	12
1896	2.9	.158	.035	.000	.054	1.8	29.5	8
1897	4.4	.191	.068	.001	.087	1.8	33.1	8
1898	3.1	.156	.030	.001	.059	2.0	32.4	8
1899	2.0	.147	.030	.000	.031	1.2	24.9	4
1900	2.3	.176	.043	.000	.039	1.4	29.2	7
KENT RESERVOIR, KETTLE BROOK.								
1898	3.6	0.176	0.012	0.001	0.042	1.6	32.0	8
1899	2.7	.239	.047	.001	.037	1.3	32.5	7
1900	3.2	.213	.037	.001	.064	1.7	32.0	8
TATNUCK BROOK RESERVOIR.								
1888	1.7	0.157	0.012	0.001	0.043	1.2	22.3	..
1889	1.9	.143	.003	.001	.031	1.2	20.4	....
1890	1.7	.141	.007	.001	.078	1.3	26.8	9
1891	1.7	.143	.024	.001	.077	1.1	23.0	4
1892	2.0	.142	.012	.000	.067	1.2	25.2	5
1893	3.5	.182	.020	.000	.049	1.4	24.5	5
1894	2.0	.151	.010	.000	.032	1.6	22.7	4
1895	2.1	.173	.012	.000	.068	1.8	23.3	5
1896	1.7	.142	.008	.000	.034	1.5	20.0	4
1897	2.1	.155	.007	.000	.054	1.6	21.2	5
1898	2.2	.141	.006	.000	.020	1.6	22.4	5
1899	1.1	.136	.013	.000	.016	1.2	20.0	2
1900	1.5	.186	.026	.000	.023	1.2	22.7	3

POLLUTION IN BLACKSTONE RIVER.

The Blackstone is the most polluted river in New England; its name has become synonymous with filth. The headwaters of a river system are usually free from pollution, but in this case the opposite is true. The sewage from the city of Worcester befouls the river almost at its source, and thereafter throughout its whole extent the Blackstone is a damaged resource to the country. Such is the accumulation of filth in the mill ponds that from some of those near Worcester there arise odors that are detrimental to comfort and realty, if not to health. The use of its water in boilers has long been abandoned, and it can not be used in the manufacture of light-colored cloths.

Worcester sewage.—The sewage of Worcester, consisting of the usual city waste and an enormous amount of manufacturing refuse, a large part of which is acid from the steel manufactories, is turned from the sewers into Mill Brook. The quantity is sufficient at times to give to the waters of the Blackstone River an acid reaction.

The water of Mill Brook above the point of sewage discharge has not been regularly examined, but it is known to be of a quality characteristic of a stream flowing through a country of considerable population, and approaching in some degree the character of the normal waters above set forth. After being polluted with the Worcester sewage the water of Mill Brook is of a vile character, as is shown in the following table of averages of monthly analyses for the years 1888–1900.

TABLE 34.—*Analyses of water from Blackstone River below mouth of Mill Brook and above outlet of sewage works.*

[Parts per million.]

Year.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1888	6.4	1.040	2.112	0.029	0.370	12.1		
1889	7.6	1.198	2.841	.024	.235	10.6		
1890	8.2	1.024	1.800	.014	.367	10.3		
1891	8.0	1.563	3.340	.032	.333	17.3	135.4	46
1892	7.1	1.262	2.530	.061	.312	18.4	162.8	49
1893	6.8	.603	1.429	.012	.180	10.4	179.5	45
1894	8.6	.570	.739	.006	.195	8.8	171.7	37
1895	8.4	.374	.507	.007	.175	8.6	134.0	29
1896	7.5	.486	.759	.010	.187	10.1	126.9	29
1897	9.4	.533	.715	.015	.151	7.7	176.2	29
1898	5.0	.557	.762	.011	.167	8.3	135.2	35
1899	2.6	.751	1.921	.010	.109	12.0	253.3	97
1900	1.8	.602	1.141	.011	.102	8.3	194.9	62

For years the city of Worcester has converted Mill Brook into an open sewer, and up to June 25, 1890, the contents were discharged directly into Blackstone River. At that time, however, a chemical precipitation works was completed by the city, and by means of a diverting dam the whole flow of Mill Brook, except during seasons of freshet, was carried across to a series of tanks, six in number, each being 100 feet long, 66.76 feet wide, and 7 feet deep. The capacity of these tanks for the treatment of sewage, according to the process adopted, was 6,000,000 gallons daily. In the year 1883 ten more tanks were added to the original six, which gave to the disposal works a nominal capacity of 15,000,000 gallons per day.

The treatment of sewage was first as follows: After being screened it was mixed with chemicals, and, passing through a mixing channel, it fell into the precipitation tanks, discharging from the first to the second, and so on through the whole series, finally being poured into the Blackstone River. The chemicals used were lime and sulphate of alumina, the former being required in large quantities when the sewage was greatly impregnated with iron. After the enlargement of the works in 1893 the process was changed slightly, the object being to secure a more thorough mixture of chemicals with the sewage before it passed into the precipitation tanks. During the year ending November 30, 1901, 3,564.7 million gallons of sewage were received at the disposal works, of which 3,133.8 million gallons were treated chemically and the remainder used for experimental work in connection with new processes of sewage disposal. The total cost of this treatment was $12.20 per 1,000,000 gallons. The chemical precipitation of sewage at Worcester is not, however, successful from the standpoint of river purification, and very little if any benefit has been apparent in the river throughout all the years during which this great expenditure has been incurred by the city. Finally the legislature of the State enacted a law requiring the city to dispose of its sewage by some other method, and experiments are now being conducted to determine a method which will effect a more satisfactory purification of Blackstone River.

Below sewage-disposal outlet.—The next recorded point of examination of the Blackstone is below the sewage precipitation works. The point of collection of the samples is nearly a mile below the mouth of Mill Brook and a considerable distance below the outlet of the precipitation works, so that the effluent has had ample opportunity to become thoroughly mixed with the river water. The following is a list of annual averages of monthly examinations during the period 1888–1900.

TABLE 35.—*Analyses of water of Blackstone River below Worcester sewage-disposal outlet.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	6.4	1.040	2.122	0.029	0.370	12.1		--
1889	7.6	1.198	2.894	.024	.235	10.6		--
1890	7.4	1.177	2.253	.016	.381	12.6		
1891	8.0	1.303	4.080	.031	.358	19.1	156.2	46
1892	5.3	1.442	3.633	.033	.278	22.1	193.5	72
1893	7.4	1.447	3.757	.070	.369	19.8	256.5	74
1894	6.0	1.309	4.228	.047	.316	21.3	257.5	79
1895	7.9	.840	2.298	.040	.347	15.2	191.4	58
1896	4.0	.930	2.645	.071	.356	19.1	242.8	83
1897	7.5	.843	2.447	.047	.300	13.3	199.4	54
1898	4.9	.725	2.260	.072	.264	13.0	194.1	66
1899	3.0	1.337	3.908	.053	.176	23.7	324.8	120
1900	2.5	1.249	4.430	.145	.110	21.3	224.7	73

Comparison of the analyses in Tables 34 and 35 shows clearly that, in spite of the so-called sewage purification carried on at Worcester at so great an expense, Blackstone River is in far worse condition below the sewage outlet than above. The amounts of free ammonia, nitrites, and chlorine at the lower sampling point are considerably greater than above the outlet of the purification works. In addition to this there are unmistakable evidences that the amount of objectionable matter from the outlet is increasing from year to year, while the conditions above constantly improve.

Uxbridge.—Again there appears a record of examinations of samples taken from the river at the upper dam of the Calumet Woolen Company at Uxbridge, 17 miles below the city of Worcester. The analyses were made monthly during the period 1888–1900, but in Table 36 the results are made up into yearly averages, as in the preceding tables, 34 and 35.

TABLE 36.—*Analyses of water from Blackstone River at Uxbridge.*

[Parts per million.]

Year	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	1.5	0.284	0.979	0.008	0.322	6.1	.....	....
1889	2.8	.300	.992	.009	.253	6.0	.....	....
1890	2.5	.214	1.168	.006	.272	6.6	.....	...
1891	2.7	.272	1.674	.008	.396	7.7	83.2	28
1892	2.1	.222	2.113	.007	.326	8.2	85.9	28
1893	4.0	.256	1.603	.029	.424	10.0	94.5	32
1894	5.1	.242	1.372	.032	.460	12.2	108.0	40
1895	6.4	.315	1.081	.037	.439	10.5	105.6	39
1896	4.2	.308	1.209	.054	.405	10.9	107.7	42
1897	5.9	.298	1.126	.035	.481	10.4	103.1	38
1898	5.8	.305	.818	.046	.360	8.4	87.2	32
1899	2.6	.374	2.298	.078	.331	15.9	140.6	56
1900	2.7	.351	2.122	.039	.359	13.8	114.3	42

It will be seen that sedimentation, dilution, and oxidation have worked improvement in the water by the time it has traversed the 17 miles, although the process during late years does not appear to be as effective as formerly. It requires only a glance to perceive that the pollution of the Blackstone is still enormous. Be it remembered, too, that, apart from the pollution at Worcester, the numerous mills along the course of the stream and the large number of employees there engaged contribute a great quantity of sewage and foul industrial waste, which of itself would be damaging to the river. Therefore the comparison of the two sets of analyses above given does not furnish an idea of the normal self-purifying ability of the river, for it is more than probable that there would appear a greater decrease in the amount of organic matter if it were not for the constant introduction of new pollution.

At Millville.—Down the river, nearly to the State line at Millville, town of Blackstone, a series of analyses similar to the one at Uxbridge has been carried on for thirteen years. This point is 24 miles from the Worcester outlet and the water is not objectionable in odor. Still, as the following analyses show, the water is polluted.

TABLE 37.—*Analyses of water from Blackstone River at Millville.*

[Average by years, in parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1888	4.7	0.253	0.444	0.005	0.242	4.4	...	..
1889	3.8	.277	.450	.004	.160	4.3	.	..
1890	3.4	.211	.587	.004	.240	4.6	.	.
1891	3.2	.293	.807	.005	.275	5.5	60.5	19
1892	3.5	.249	.896	.004	.218	5.4	60.3	18
1893	4.0	.288	.899	.008	.289	6.6	62.3	20
1894	4.9	.219	.528	.008	.232	7.3	63.7	25
1895	5.8	.253	.501	.016	.278	7.4	74.7	27
1896	4.0	.248	.549	.018	.347	7.6	73.4	28
1897	5.3	.262	.528	.014	.332	7.3	70.7	26
1898	5.5	.256	.456	.016	.222	6.1	64.3	23
1899	2.8	.267	.985	.029	.220	8.8	89.5	32
1900	3.6	.288	1.194	.023	.272	9.3	83.2	29

In Rhode Island.—As Blackstone River passes out of the State of Massachusetts, it comes within the polluting influence of Woonsocket, R. I., a city of 28,000 inhabitants, situated a short distance south of the State line. From this point to its outlet in Providence it flows through a thickly settled country, which, while it contributes no large amount of raw sewage to the river, does not, nevertheless, permit so extensive a purification of its water as might be effected in a country having a smaller population.

The State of Rhode Island, through its board of health, has attempted to supplement the Massachusetts work by making periodical analyses of the water of the river at two different points—one at Albion, a short distance below Woonsocket, and the other at Valley Falls, nearer Providence. The results of these analyses are given in Table 38.

TABLE 38.—*Analyses of water from Blackstone River at Albion and Valley Falls, R. I.*

ALBION.

[Average by years, in parts per million.]

Year.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
	Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	0.235	0.156	0.040	0.800	11.0	75	21.7
1895	.260	.127	.....	.560	10.5	81	21.3
1896	.220	.204	.030	.780	.9	72	16.0
1897	.220	.223	.030	.650	7.7	75	14.0
VALLEY FALLS.							
1894	0.261	0.117	0.070	0.824	12.0	66.5	17.6
1895	.201	.139	.070	.500	10.8	69.0	22.4
1896	.200	.196	.070	.070	.9	85.0	16.0
1897	.220	.215	.040	.070	.8	74.0	15.0

The results expressed in Table 38 do not inspire confidence in their accuracy, and it is highly probable that the tables presented in the report of the State Board of Health for 1897 are typographically incorrect. On comparing the results with those taken from the Massachusetts reports it will be seen that the nitrites are enormously high, averaging greater than the amounts found below the Worcester sewage outlet. It is extremely unlikely that these results are correct, because of the fact that the water shows decided improvement as it flows from Worcester town to the Rhode Island line, and south of that there is no increment of sewage which would by any means give to the nitrites the enormous figure which appears in the above analyses. The chlorine determinations, too, show improbable fluctuations.

On the other hand, the amounts of free and albuminoid ammonia, which would necessarily fluctuate to some extent at least with the nitrites and nitrates, do not appear excessive.

CONNECTICUT RIVER BASIN.

NATURAL RESOURCES.

Course and drainage area.—The Connecticut is the largest river in New England. From its source in the Connecticut lakes in the extreme northern part of New Hampshire to its mouth in Long Island Sound the course of the river measures 375 miles. The drainage area is long and narrow, being from 40 to 60 miles in width and covering 10,924 square miles (see fig. 7). The character of the country

varies from the rolling surface common to Massachusetts to the hilly or mountainous country of New Hampshire and Vermont. The rocks are granite, gneiss, syenite, and mica, intersected by dikes of trap and red sandstone. Along the course of the river in Massachusetts and Connecticut there are rich alluvial deposits, but for the most part the basin of the Connecticut is covered by surface drift. Lakes are abundant on most of the branches, and the flow of the main river is fairly steady.

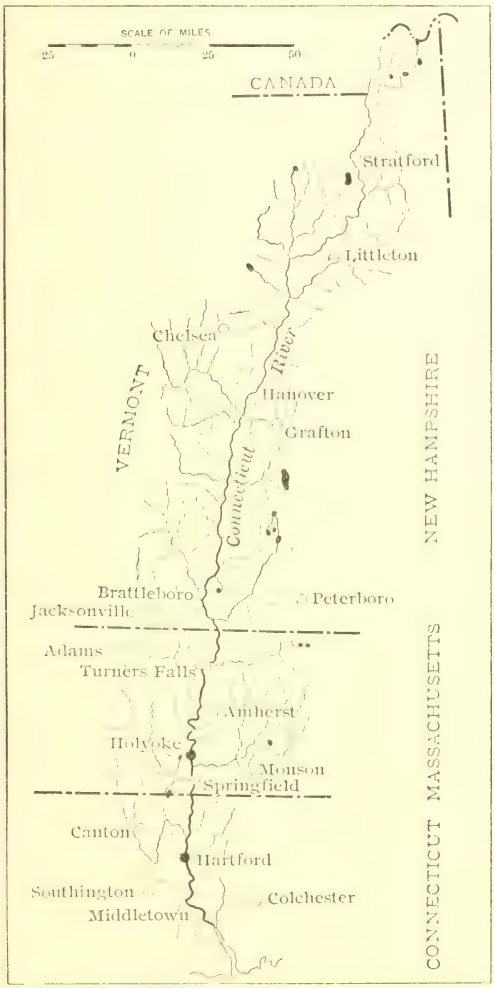

FIG. 1. Connecticut River drainage basin.

The course of the Connecticut is varied. From its source for a distance of 200 miles downstream the river contains many falls and rapids, the last one being at Bellows Falls, Vt. Below this place the fall in the stream is much less, yet the pitch is sufficient to give the water a fairly good flow. Throughout the extent of the river below Bellows Falls the course of the river is broken by falls in three places, Turners Falls and Holyoke, Mass., and Windsor Locks, Conn. The power developed at Holyoke is the largest in the country, except that at Niagara.

Transportation.—The river has considerable importance in the lower end as a means of transportation. Navigation extends 30 miles from the mouth up to Hartford, and small boats may ascend, by means of Windsor Locks, as far as Holyoke. Travel, however, above Hartford is insignificant, while even in the lower stream large vessels have difficulty in low tide.

Power.—As a source of power the value of the Connecticut is enormous. The main river, with a total fall of 2,038 feet, has been largely utilized, but there remain possibilities for further development which,

if advantage were taken of them, would make the Connecticut one of the most valuable streams in the world. The tributaries have been developed extensively, and the possibilities for the future are promising.

In the following table, taken from Water-Supply and Irrigation Paper No. 44, there is presented a detailed statement of the altitude and fall per mile at different points along the river:

TABLE 39.—*Fall of Connecticut River.*

Locality.	Distance from mouth.	Height above sea.	Fall per mile.
	Miles.	*Feet.*	*Feet.*
Mouth	0	0	.....
Hartford	50	0	.....
Foot of Enfield Rapids	60	6	0.6
Top of Enfield dam	66	38	5.3
Top of Holyoke dam	84	98	3.3
Fitchburg Railroad crossing	115	109	.35
Top of Turners Falls dam	120	173	12.8
Mouth of Ashuelot River	136	206	2.1
Westmoreland	159	219	.6
Foot of Bellows Falls	170	234	1.4
Head of Bellows Falls	170	283	....
Beaver Meadows, Charlestown	181	289	.5
Windsor	196	304	1.0
White River Junction	209	339	2.7
Ledyard bridge, Hanover	213	375	9.0
Oxford	230	380	.3
Wells River	255	407	1.1
Foot of McIndoes Falls	262	432	3.6
Lower Waterford	273	643	19.2
Head of Fifteenmile Falls	285	830	15.6
North Stratford	312	885	2.0
West Stewartstown	344	1,035	4.7
Connecticut Lake	361	1,618	34.3
Second Lake	369	1,882	15.5
Third Lake	375	2,038	26.0

The following table contains a statement of the total utilized horsepower and the drainage area of the most important tributaries of the Connecticut.

TABLE 40.—*Drainage area and utilized horsepower on the Connecticut River tributaries.*

Tributary.	Horsepower utilized.	Drainage area.	Tributary.	Horsepower utilized.	Drainage area.
		Sq. miles.			*Sq. miles.*
Salmon River	1,432	150	Ottaquechee River	1,723	192
Hockanum River	3,957	79	Mascomy River	1,576	190
Little River	555	76	White River	2,714	623
Farmington River	8,856	584	Ompompanoosuc River	493	123
Scantic River	1,122	118	Waits River	596	156
Westfield River	3,910	514	Lower Ammonoosuc River	2,526	388
Chicopee River	4,044	706	Wells River	628	94
Mill River	1,161	58	Passumsic River	4,724	485
Deerfield River	4,352	646	Johns River	168	86
Millers River	8,172	369	Israels River	974	129
Ashuelot River	3,964	422	Upper Ammonoosuc River	548	252
West River	1,947	363	Nulhegan River	240	132
Williams River	361	103			
Black River	2,132	152			
Sugar River	3,176	272			

FLOW.

The flow of the river has been carefully measured and a concise statement appears in Part IV of the Twentieth Annual Report of the United States Geological Survey, page 47.

TABLE 41.—*Flow of the Connecticut River at Holyoke during the years 1880–1898, inclusive.*

[Drainage area, 8,660 square miles.]

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1880	44,100	300	8,343	0.96	12.89
1881	49,050	450	9,818	1.13	15.53
1882	45,000	250	10,018	1.14	15.40
1883	68,300	250	8,107	.94	12.70
1884	71,900	500	13,084	1.51	20.46
1885	63,950	2,950	12,635	1.46	19.65
1886	80,150	550	11,387	1.31	17.73
1887	85,500	3,300	14,329	1.65	21.32
1888	99,750	1,100	17,320	2.00	27.15
1889	37,650	1,350	13,903	1.59	21.50
1890	46,750	550	15,556	1.78	24.12

TABLE 41.—*Flow of the Connecticut River at Holyoke, etc.*—Continued.

Year.	Maximum.	Minimum.	Mean.	Run-off.	
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft. per sq. mi.*	*Inches.*
1891	67,300	900	13,190	1.51	21.48
1892	63,100	1,800	12,273	1.48	20.15
1893	94,350	750	10,295	1.19	16.19
1894	43,300	150	8,397	.97	13.17
1895	115,000	350	10,314	1.20	16.19
1896	112,050	450	12,394	1.43	19.41
1897	75,350	1,300	15,373	1.78	24.17
1898	76,150	600	13,844	1.60	21.70

Water supply.—Although a comparatively small part of the drainage area of the Connecticut has been set apart and developed as a source of water supply, the value of the resources within its basin are readily apparent. None of the cities along the main stream pump their supply from the river direct, but in the areas of the tributaries numerous reservoirs have been constructed from which are obtained water supplies of excellent quality. These will be taken up in the discussion of the different branches.

Ice.—The ice values in the Connecticut system are extensive. The same statements that were made in connection with this subject in the discussion of the Merrimac apply here. The main river has not been used largely as a source of ice supply. That it would be more acceptable than some rivers, as the Hudson, Kennebec, and Penobscot, which have been largely developed in this direction and yield enormous amounts annually, is very probable, yet it is the practice of the consumers in the Connecticut Valley to refuse to accept ice from the main stream. Therefore the small streams, ponds, and lakes within convenient distances from each municipality have been utilized. There is no estimate of the value of the ice crop in the Connecticut basin.

Character of water.—The character of water in the main river is of course largely determined by that from the tributaries feeding it, and as the water in the latter varies widely in different regions, that in the Connecticut proper is dependent upon the distance of a given sampling point from the confluence of a normal or a polluted branch. Below the entrance of a tributary loaded with sewage and manufacturing wastes the condition of the water is inferior to that at a point where it has been diluted by an influx of pure water from an unpolluted tributary.

Little or no attention has been given to the tributaries entering the main artery above the Massachusetts State line, and the highest branch concerning which we have information is Millers River.

MILLERS RIVER.

Millers River (see fig. 8) enters the Connecticut from the east at a point in Massachusetts about 10 miles south of the New Hampshire line. Its basin adjoins that of the Chicopee on the south and extends over into the State of New Hampshire on the north, covering about 395 square miles. The drainage area is hilly, especially near the river's confluence with the Connecticut, but farther back there are large areas of flat land. Lakes and ponds are plentiful, having a total area of 3,200 acres.

The flow of the river is very steady and its consequent value as a power stream is large. From Winchendon, near its headwaters, to its mouth there is a fall of 775 feet, the distance being not more than 30 miles. All of this fall is not available for development, however,

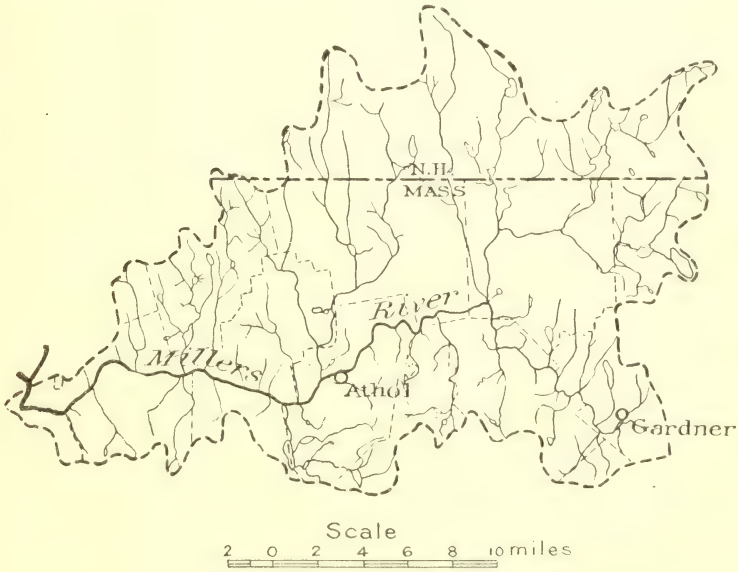

FIG. 8.—Millers River drainage basin.

as the course of the river for considerable distances partakes of the nature of a ravine; the banks are high and steep and little opportunity is afforded for the establishment of mills. The only available flow measurements are those made during October, November, and December, 1887, at the dam of the New Home Sewing Machine Company, at Orange. During this period the average monthly flow varied from 1.10 to 1.45 cubic feet per second per square mile. The population in the basin of Millers River is about 96 per square mile. This, however, does not fairly represent the conditions at the upper end of the area, for there the population is extremely dense, especially at Gardner. During the decade 1890–1900 there was a fair percentage of increase in the towns drained by this river, although it was for the most part confined to the towns of Gardner, Athol, Orange, and Win

chendon, while there was a decrease in the remaining places. Water supplies have been established at the above-named places, while sewerage systems have been laid at Orange and Gardner. These facts make it patent that Millers River receives considerable pollution, and, as the greatest population is near the headwaters, the river is unfitted for several uses throughout its whole length.

NORMAL WATER IN MILLERS RIVER.

It appears from the Massachusetts map of normal chlorine that the normal for Millers River varies from 0.8 to 1.2 parts per million, averaging about 1. Reports of the analyses of normal water are not plentiful for this drainage area, the only one appearing in the Massachusetts reports is of the well at the waterworks at Winchendon. This and several others in which the amount of chlorine does not greatly exceed the normal are reproduced in the following table:

TABLE 42.—*Analyses of normal water in Millers River drainage area.*

[Parts per million.]

Location.	Color.	Nitrogen as—				Chlorine.	Residue on evaporation.	Hardness.	Number of analyses made.
		Ammonia.		Nitrites.	Nitrates.				
		Albuminoid.	Free.						
Well in Winchendon	0.33	0.012	0.004	0.000	0.043	1.1	31.4	11	18
Orange waterworks	1.6	.112	.010	.000	.019	1.3	30.6	6	32
Athol waterworks	6.9	.342	.067	.000	.049	1.3	38.1	6	8
Gardner waterworks	.7	.161	.014	.000	.055	3.3	30.3	10	([a])

[a] Covering eight years.

The characteristics of the waters represented in the foregoing table are well shown. They are all acceptable for any of the ordinary uses and retain all the values of natural waters. The first and only normal water in the list is a well water. That it is a typical well water is shown by the color, which is very faint, practically absent. The low content of free and albuminoid ammonia is what might be demanded in a well water, and the evidences of its condition are further borne out by the absence of nitrites.

The Athol and Orange waters are from impounding reservoirs, and therefore are largely made up of surface drainage. The analyses show that oxidation had been rapid and that the character of the water is acceptable. The chlorine is above the normal, not very much to be sure, but sufficient to denote that the drainage area of the reservoirs has a certain population which contributes sewage to the natural drainage, and although its bad effects have long since been washed

away the traces still remain and neither water can be classed as normal.

The analysis of the Gardner water is instructive. It is apparently a water which has at some time been highly polluted, but which, through filtration, sedimentation, etc., has been reclaimed. The amount of chlorine, 3.3 parts per million (the normal for this country being 1.2) is unmistakable evidence of past pollution. In the previous pages mention has been made of waters which have been redeemed from contamination by means of artificial filters, but this is the clearest case noted in which the work has been done by natural conditions only.

Parts of the drainage basin of Millers River are thickly settled, which will account for the fact that none of the surface waters thus far analyzed are normal. The amount of chlorine found in a surface water bears a direct relation to the number of persons dwelling upon the land drained by that water. It follows, then, that while it may be impossible in a thickly settled country to secure normal water in large quantities, it is not necessarily impossible to so dispose of the wastes from the inhabitants that the resulting surface water may serve all purposes to which normal waters are applicable.

POLLUTION IN MILLERS RIVER.

The water of Millers River has been examined regularly by the Massachusetts State Board of Health at a point above Athol, where the pollution from Gardner and Winchendon may be detected, and again at a point below Orange, where the water contains the pollution from Gardner, Winchendon, Athol, and Orange. The analyses at these points are reported in Tables 43 and 44.

TABLE 43.—*Analyses of water from Millers River above Athol.*

[Parts per million.]

Date of collection.	Appearance.			Residue on evaporation.		Ammonia.				Chlorine.	Nitrogen as		Oxygen consumed.	Hardness.
							Albuminoid.							
	Turbidity.	Sediment.	Color.	Total.	Loss on ignition.	Free.	Total.	Dissolved.	Suspended.		Nitrates.	Nitrites.		
1900.														
July 17	Very slight.	Very slight.	6.1	36.0	15.0	0.072	0.264	0.240	0.024	2.0	0.010	0.000	8.1	5
Aug. 21	Decided	Considerable.	7.8	51.0	21.0	.032	.480	.344	.136	1.2	.030	.004	10.3	11
Sept. 19	do	do	7.0	64.5	17.5	.020	.775	.268	.507	1.4	.100	.002	6.7	11
Oct. 16	Very slight.	Very slight.	8.7	64.5	24.0	.048	.300	.284	.016	1.9	.110	.000	12.5	18
Nov. 20	Slight	do	7.2	53.0	17.0	.028	.360	.204	.156	1.9	.120	.000	10.9	14
Dec. 20	Very slight.	Considerable.	5.0	37.5	15.0	.018	.318 .416	.160	.158	1.2	.100	.000	7.5	16
Average			7.0	51.1	18.2	.036	.416	.250	.166	1.6	.078	.001	9.3	12

TABLE 44.—*Analyses of water from Millers River below Orange.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1900.									
July 24	Slight	5.9	0.292	0.064	0.002	0.010	2.8	35.0	5
August 22	Very slight	7.0	.292	.046	.001	.050	2.4	43.5	6
September 21	do	5.4	.240	.060	.001	.040	2.1	43.0	6
October 24	do	9.0	.376	.064	.002	.030	2.6	55.5	11
November 20	do	9.5	.284	.056	.001	.060	2.6	45.0	11
December 24	Decided	6.0	.260	.124	.000	.130	2.1	45.0	6
Average		7.1	.291	.069	.001	.053	2.4	44.5	7

DEERFIELD RIVER.

The Deerfield is the second largest tributary of the Connecticut. It rises in southern Vermont, crosses the Massachusetts State line, and, a few miles across, turns eastward and enters the Connecticut about 7 miles below the mouth of Millers River. The river has been little developed, and for the most of its length runs wild and free. There are many good and available power privileges, the slope is rapid, and the country is conveniently traversed by railroads, yet very few industries have been established in it. The elevation of the Deerfield at Readsboro, Vt., at the mouth of the West Branch, is 1,154 feet, while 42 miles below, at its mouth, its elevation is about 126 feet. There is practically no storage upon the drainage area in Massachusetts and very little in Vermont, therefore the flow is variable. In many places where power sites are otherwise excellent the valleys are too narrow for the location of mills. The river drains 656 square miles.

The total population of the basin is about 24,400, or approximately 37 per square mile. There is no important city within the watershed. Garfield, with a population of 7,927, is the largest place, but it is at the mouth of the Deerfield, and is also drained by the Connecticut itself. Shelburne and Colerain are next in size, with 1,508 and 1,749 inhabitants, respectively. Shelburne Falls is the only manufacturing town in the drainage area, although there are powers developed at Hoosac and Readsboro. There are no sewerage systems in the basin, the country is not highly fertile, and these facts, taken together with the sparse population, indicate clearly the character of the water.

The Deerfield is, in effect, another river system which has been preserved in practically its original condition, with all its normal resources unaffected.

Few analyses are available to show the character of the water of the Deerfield. These are included in Table 45.

TABLE 45.—*Analyses of water from Deerfield River at various points.*

[Parts per million.]

Number.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Place of collection.
1	None		0.095	0.024	0.000	0.130		28.0		Above Readsboro.
2	Very slight		.120	.020	.000	.020		29.0		Monroe.
3	do	3.7	.110	.004	.000	.120	0.5	28.5	5	Florida.
4	do	.8	.085	.011	.000	.160	1.1	48.0	24	Colerain.
5		.7	.054	.008	.000	.102	1.0	49.1	28	Leyden.
6		3.2	.120	.008	.000	.097	1.0	36.0	17	Above Shelburne Falls.

Comment on the results set down in Table 45 seems unnecessary. The waters there represented are practically normal, the evidence of sewage pollution being very faint and the polluting substances having been practically all reduced to inorganic matter.

CHICOPEE RIVER.

The Chicopee is formed at Three Rivers by the union of the Quaboag, Ware, and Swift rivers. The Quaboag is the most southerly, and drains 210 square miles; the Ware drains 214 square miles, while the basin of the Swift covers 219 square miles. The total discharge averages 669 cubic feet per second.

Drainage area.—The drainage area of the Chicopee (see fig. 9) is larger than that of any other tributary of the Connecticut, comprising 706 square miles in central and southern Massachusetts, and occupying large portions of Worcester, Franklin, Hampshire, and Hampden counties. The country is fairly prosperous, and has constantly increased in population since the middle of the last century. During recent decades this increase has been confined to the cities and large villages, the rural population having decreased considerably. The country is very accessible, being traversed by excellent railroad systems, which have been of value to the power facilities of the river. It is hilly, with open valleys, the soil being principally bed gravel crossed by ledges of red sandstone, which form numerous falls in the rivers that flow through the district. The slope of the rivers throughout the whole system averages 15 feet per mile, but the maximum for certain sections is far greater than this.

Ponding.—There are in the basin many natural reservoirs, which serve to maintain comparatively steady flow in the streams. There

FIG. 9.—Chicopee River drainage basin.

is also considerable swamp land, especially along the Quaboag River, which materially assists in the maintenance of a uniform rate of flow.

TABLE 46.—*Principal ponds in basin of Chicopee River.*

Locality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
Prescott	On West Branch of Swift River.	154	West Branch of Swift River.
New Salem	Thompsons Pond	235	Middle Branch of Swift River.
Greenwich	Curtis Pond	155	Do.
Do	Luce Pond	124	Do.
Do	West Pond	94	Do.
Petersham	Reservoir (no name given)	175	Do.
Dana	Neeseponsett Pond	118	Do.

TABLE 46.—*Principal ponds in basin of Chicopee River*—Continued.

Locality.	Name of pond.	Area.	Tributary to what stream.
		Acres.	
Greenwich	Davis Pond	100	East Branch of Swift River.
Dana	Pottapang Pond	160	Do.
Phillipston	Phillipston Pond	202	Burn Shirt River (to Ware).
Do	Pond northeast of above	130	Do.
Hubbardston	Reservoir near Westminster.	90	Ware River.
Do	Moosehorn Pond	160	Do.
Do	Asuyconie Pond	238	Do.
Hardwick	Muddy Pond	202	Do.
Barre	Reservoir (no name given)	200	Do.
Rutland	Pond west of center	135	Do.
Do	Long Pond	160	Do.
Do	Demon Pond	138	Do.
New Braintree	Two ponds near center	94 75	Quaboag River.
Oakham	Browning Pond	140	Do.
West Brookfield	Wickaboag Pond	323	Do.
North Brookfield	Brooks Pond	178	Do.
Do	Furnace Pond	305	Do.
Brookfield	Podunk Pond	508	Do.
Do	South Pond	340	Do.
Spencer	Cranberry Meadow Pond	107	Do.
	Total area of 28 ponds.	5,040	

Power values.—The Tenth Census Report on Water Power contains an excellent description of the power utilized on the Chicopee. It states that the main river is an extremely valuable one, and has gained prominence by reason of the extensive cotton and other manufacturing industries established along its course. The available fall in the river has been practically all utilized. Of the three main branches the Quaboag is the most valuable for power because of its well-sustained flow, the value of the Ware and the Swift rivers following closely in the order named.

Character of water in the Chicopee Basin.—The following towns are situated partly or wholly within the Chicopee Basin: Chicopee, Ludlow, Belchertown, Palmer, Monson, Wales, Brimfield, Warren, Brookfield, West Brookfield, North Brookfield, Spencer, Paxton, New Braintree, Ware, Enfield, Hardwick, Oakham, Greenwich, Prescott,

Pelham, Shutesbury, Dana, Barre, New Salem, Wendell, Petersham, Phillipston, Templeton, Hubbardston, Rutland, Wilbraham, and Springfield.

The population in the drainage area is about 90,000, or 127 per square mile.

WARE RIVER.

The watershed of Ware River adjoins that of the Nashua. It has an elevation in the towns of Oakham and Barre of about 645 feet above high tide. The population is small and the pollution is therefore not objectionable, and from a sanitary point of view the stream is an excellent source of water supply. The area has been considered a favorable one by the Metropolitan Water Board of Massachusetts as a part of the natural gathering ground for the future supply of Boston and the vicinity. It forms a link in the chain of gathering grounds in central Massachusetts, which will at some day in the future, when the demands require it, be connected with the Nashua and the waters carried through the long aqueducts to the distribution stations in the vicinity of Boston.

Analyses have been made periodically by the Massachusetts State Board of Health of the water in Ware River at Coldbrook station, in the town of Barre. The average results for each year are included in Table 47.

TABLE 47.—*Analyses of water from Ware River at Coldbrook station at Barre.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of analyses made.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1894	7.4	0.178	0.005	0.000	0.023	1.4	35.5	8	12
1895	7.8	.219	.014	.000	.051	1.7	39.6	9	12
1896	7.2	.198	.003	.000	.038	1.1	33.6	8	6
1897	8.3	.193	.010	.000	.032	1.4	36.0	7	12
1898	7.6	.196	.011	.000	.027	1.4	35.1	7	12
1899	5.0	.184	.010	.000	.032	1.4	33.8	4	12
1900	6.2	.227	.025	.000	.014	1.4	36.6	5	7

The color of the water is fairly high, due, no doubt, to a considerable extent of swamp land. The amount and condition of the organic matter is not particularly suggestive, save that the free and albuminoid ammonia in 1900 is higher than in previous years, showing additional organic pollution, the source of which is not apparent. The normal chlorine for this region is from 1.1 to 1.2 parts per million, so

that the average of 1.4 parts in the table above set forth shows a slight sewage contamination.

In the basin of Upper Ware River is Musquapog Lake, the source of the water supply of Rutland. The following analyses were made of the water from this lake in the year 1900:

TABLE 48.—*Analyses of water from Musquapog Lake.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 31	Very slight	0.2	0.118	0.098	0.001	0.010	1.6	17.5	5
Aug. 14	do	.1	.188	.010	.000	.000	1.4	17.0	2
Sept. 26	do	.2	.130	.044	.000	.020	1.4	21.0	3
Dec. 20	do	.2	.218	.070	.001	.030	2.8	29.0	5

The water supply of Barre is collected in a reservoir within the town, the water flowing from several springs in the vicinity and from the surface of the ground for a considerable area above. Analyses of this water, made in 1898, are reported as follows:

TABLE 49.—*Analyses of water from the reservoir of the Barre Water Company.*

[Parts per million.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1898.									
Jan. 11	Decided	1.5	0.096	0.002	0.000	0.000	1.4	25.0	10
Apr. 12	do	1.1	.272	.018	.002	.002	1.5	19.0	8
July 5	Slight	1.1	.330	.042	.001	.001	1.3	25.0	5
Oct. 5	do	1.0	.536	.156	.000	.020	1.4	25.0	8
Average		1.2	.308	.054	.001	.032	1.4	23.5	8

Ware River, after flowing by the town of Barre, which has a population of over 8,000, plainly shows the effects of pollution. A large number of the houses and some of the factories of Ware empty their wastes directly into the river. Analyses of samples of water taken from the river below the town, made by the State Board of Health, in the year 1900, are given in table 50. When these are compared with those made of the water collected at Cold Brook Station the change is clearly illustrated.

TABLE 50.—*Analyses of water from the Ware River below Ware.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Slight	4.1	0.312	0.060	0.008	0.000	2.1	46.5	10
August 22	Decided	3.7	.324	.032	.002	.040	2.2	45.0	8
September 26	do	3.4	.404	.076	.003	.020	3.3	52.0	11
October 16	Very slight	7.3	.288	.052	.002	.040	2.4	54.0	11
November 19	Decided	7.0	.275	.110	.001	.050	2.5	49.0	14
December 19	do	5.0	.288	.132	.002	.120	2.5	51.0	11
Average		5.1	.315	.077	.003	.045	2.5	49.6	11

Not far below the point where these samples were collected Ware River joins the Swift and the Quaboag. The analyses in table 49 therefore represent the character of the water contributed by the Ware River to the Chicopee system.

SWIFT RIVER.

Swift River is the westernmost of the three main branches of the Chicopee. Below the town of Enfield it has an elevation of 376 feet above tide. It drains an area of 185.7 square miles, which has a population of 128 per square mile. This area, like that of the Ware, has been considerd as a source of water supply by the Metropolitan Water Board. The water is of excellent quality and has little color. The following analyses have been made by the State Board of Health of Massachusets.

TABLE 51.—*Analyses of water from Swift River at designated points.*

[Parts per million.]

Date.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
EAST BRANCH IN GREENWICH.									
1894	4.7	0.146	0.011	0.000	0.015	1.5	31.0	8	2
MIDDLE BRANCH IN GREENWICH.									
1894	3.8	0.115	0.012	0.000	0.000	1.3	31.5	9	2
BARRETTS JUNCTION.									
1900	3.2	0.167	0.012	0.000	0.040	1.6	33.3	10	3
TOWN OF ENFIELD.									
1898	0.4	0.030	0.000	0.000	0.058	1.1	25.8	7	6

QUABOAG RIVER.

The Quaboag is the southernmost of the three main branches of the Chicopee. It drains the whole area of the towns of Monson, Brimfield, New Braintree, Oakham, Spencer, and Paxton. The population per square mile is 125, which is considerably larger than in the Ware and Swift basins. The character of the unpolluted water in the drainage area of the Quaboag is well shown in the following series of analyses:

TABLE 52.—*Analyses of unpolluted water in Quaboag Basin.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
Reservoir, Monson	1.1	0.355	0.030	0.004	0.105	1.7	34.5	...
Shaw Pond, Spencer	.3	.136	.007	...	.059	1.4	26.9	...
Dug well, Monson	.1	.011	.002	.000	.095	1.2	33.3	10
Do	.0	.006	.001	.000	.078	1.3	32.2	7
Spring, North Brookfield	.0	.008	.010	.000	.245	1.4	37.0	9
Doane Pond, North Brookfield	5.3	.308	.145	.002	.050	1.2	31.5	4
Shaw Pond, Spencer	.3	.148	.018	.000	.090	1.6	22.2	5

The settlements along the Quaboag which contribute a considerable amount of matter to the river above the town of Palmer are Spencer, Brookfield, North Brookfield, Warren, and Monson. After the water has passed all these points it is in the condition indicated in the following table:

TABLE 53.—*Analyses of water from Quaboag River above Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1900.									
July 17	Very slight	4.4	0.196	0.040	0.001	0.010	1.9	41.0	11
August 21	Slight	5.1	.236	.032	.001	.010	2.5	47.0	10
September 19	Very slight	3.5	.208	.028	.001	.030	2.8	42.5	13
October 29	Slight	4.4	.248	.048	.002	.040	3.1	45.0	14
November 20	do	4.3	.216	.036	.000	.110	2.9	44.5	17
December 18	do	4.5	.198	.010	.003	.100	2.5	42.5	11
Average		4.4	.217	.032	.001	.050	2.6	37.7	13

After receiving considerable sewage from Palmer, the river below is not apparently in a worse condition from the standpoint of organic content than it was above that town. This fact is shown by the following analyses:

TABLE 54.—*Analyses of the water of the Quaboag River below Palmer.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1900.									
July 17	Very slight	4.1	0.180	0.040	0.001	0.030	1.8	41.0	13
August 21	Slight	5.0	.246	.044	.001	.050	2.4	51.5	8
September 19	Very slight	3.1	.198	.008	.001	.050	3.0	44.0	13
October 29	Slight	4.0	.248	.048	.002	.040	3.1	47.0	10
November 20	Decided	3.7	.216	.048	.000	.140	2.9	44.5	10
December 18	Slight	4.1	.190	.008	.003	.120	2.5	43.5	11
Average		4.0	.213	.033	.001	.072	2.6	45.2	12

A comparison of the two tables shown above illustrates in a fairly clear way a point made at the beginning of this discussion, which is, that analysis of water is not always effectual in showing its condition from the standpoint of general healthfulness. It is plain that the water of Quaboag River can not be as safe for public use after it has passed the town of Palmer as it was above this point. The amount of pollution from Palmer is rather extensive, but it is not apparent in the analysis of the water. The reason for this is probably that the amount of pollution is not sufficient to appreciably change the quantity of organic matter contained in so large a flow as that of the Quaboag, yet it is undoubtedly true that if the germs of any water-borne disease, such as typhoid fever, were brought into the river from Palmer, the use of the water below Palmer would be extremely dangerous, even though the analysis would seem to show that, from the standpoint of organic content, the river had not changed.

From the confluence of the Swift, Ware, and Quaboag rivers the Chicopee runs almost due west, past the municipalities of Ludlow, Wilbraham, Chicopee, and Springfield. The first village below Three Rivers is Ludlow, from which there is considerable sewage emptying into the Chicopee. The average of six analyses of the water below Ludlow made in the year 1900 is reported as follows:

TABLE 55.—*Analyses of water from the Chicopee River below Ludlow.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900	3.8	0.240	0.042	0.012	0.098	2.8	46.0	12

After receiving sewage from Indian Orchard, Chicopee Falls, and a part of Chicopee the river enters the Connecticut. No recent analyses of the water of the river at a point below that are available.

WESTFIELD RIVER.

Drainage basin.—Westfield River is a branch of the Connecticut which enters the latter from the west at a point opposite Springfield, Mass. (See fig. 10.) It has a drainage area of about 515 square miles, all of which is situated within the State of Massachusetts. Above a point 16 miles from the mouth of the river the country is extremely hilly, and in the upper districts it is even mountainous. The maximum fall from source to mouth is, where measured via the West Branch, about 1,162 feet, or an average of 32.5 feet per mile. In the

upper part of the river, however, the fall averages usually 70 feet per mile.

The rainfall on the watershed finds its way over the steep slopes rapidly and the flow of the river fluctuates in consequence. This flood flow is not steadied by any considerable storage within the basin, for there are few natural ponds or lakes, and little or nothing has

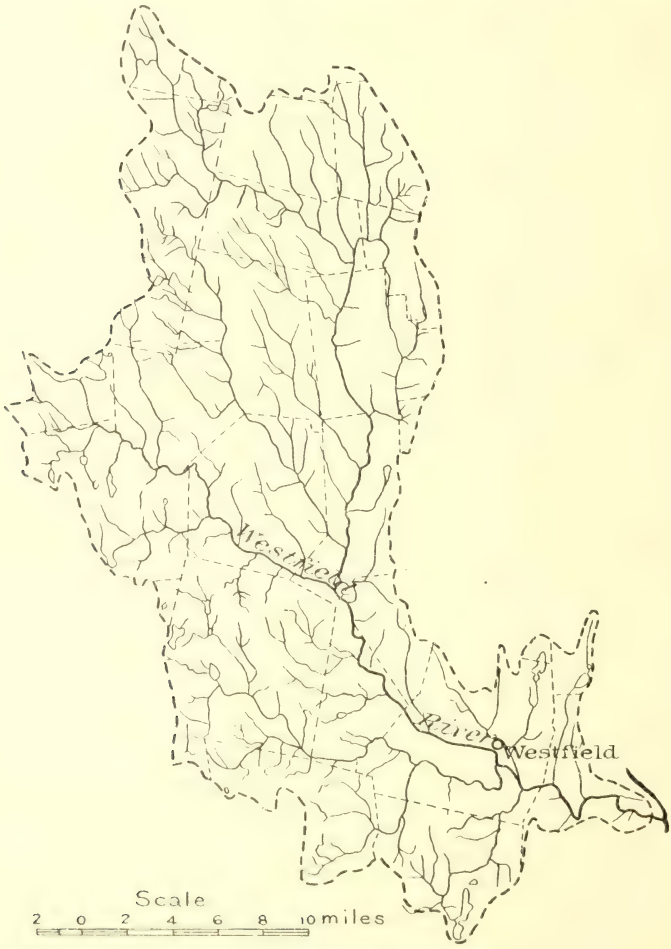

FIG. 10.—Westfield River drainage basin.

been done to impound the waters. Gen. Theodore G. Ellis, Chief of Engineers, U. S. Army, has given the average flow of the river as 500 cubic feet per second, but this is believed by Professor Porter to be too large.

Population.—The development of the drainage area of the Westfield has been slow and the growth of population slower. In a great majority of the towns there has been a decrease in the number of

inhabitants within the decade 1890–1900. A large part of the basin has no railroad facilities whatever, and there has been no need of any. In short, the country has not shared the industrial and commercial advancement which has been made by the greater part of the surrounding sections. In the lower parts of the area, notably in Westfield, there has been an increase in population amounting to 25 per cent in the last decade. Exclusive of this town and West Springfield, the most populous part of which drains into the Connecticut, the drainage area has a population of about 23 per square mile.

Character of water.—On account of the small population the character of the water is excellent, and the river above the town of Westfield may be considered practically unpolluted. The following expressive statement is found in the report of the State Board of Health of Massachusetts for 1890:

> Analyses of the water of the Westfield River have not been made regularly, because it was polluted so little during the time covered by these investigations (1887–1889) that it seemed unnecessary.

As above noted, conditions in the river have not changed, except in the lower end; therefore the passage quoted applies at the present time. The construction of a sewerage system at Westfield and the location of its outlet in the river has made it necessary to examine the waters above and below the outlet in order to show the effect upon the river. In the investigation of water supplies for different towns in the district, several analyses of water in the drainage basin were made.

TABLE 56.—*Analyses of normal water of the Westfield River system.*

[Parts per million.]

Point of taking sample.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.	Number of samples analyzed.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Chester	None	0.9	0.068	0.004	0.001	0.120	1.0	32.5	11	1
Huntington (Middle Branch).	do	.9	.063	.004	.000	.043	.9	32.1	15	14
Huntington (East Branch)		1.4	.087	.005	.000	.053	1.0	33.2	14	14
Russell	Very slight.	1.2	.078	.010	.000	.070	.7	32	1	1
Granville		1.3	.071	.013	.000	.027	1.2	26.7	4	14

The above analyses represent the characteristics of water, which may fairly be called normal, obtained from different parts of the drainage area. It will be seen that there is very little difference in the color of the various samples and that the residue and the albuminoid ammonia are remarkably uniform. The Granville sample shows higher free ammonia and chlorine than the preceding ones, which for the moment looks threatening, but it will be seen that the actual departure from the normal is wholly within the limits of error, and if there is any pollution in the Granville sample it is not sufficient to produce significant changes, so that the water from nearly the whole Westfield area is of practically normal character. The basin remains in a condition in which may be realized all the resources which its streams can provide. The public demand for drinking water may be met at almost any point, and there is no blemish on the ice fields. The manufacturer may use the water with impunity, for it is not changed sufficiently to injure his products. That this district, lying between the metropolitan area of New York and the prosperous country of central Massachusetts, should remain throughout its greater part in normal condition is worthy of remark.

We will now trace the changes that take place in the water of Westfield River after it passes the town of Westfield, with its population of 12,310.

TABLE 57.—*Analyses of water from Westfield River above and below Westfield.*

[Parts per million.]

Point of taking sample.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Number of samples examined.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
Above Westfield	2.2	0.135	0.013	0.000	0.035	1.3	42.6	19	15
Below Westfield	2.0	.296	.128	.004	.069	2.3	49.9	23	11

The analyses in the table above are of peculiar interest, as they show the effect of a single sewerage system on a pure stream. From what has gone before it will be remembered that Westfield River receives practically no significant pollution until it reaches the city of Westfield, but in passing the city it is changed from a normal river to a polluted one. Let us consider the significance of the determinations in Table 57. The average of the samples taken below the city shows a great increase in the amount of polluting material. Free ammonia, nitrites, and chlorine, the special indicators of the presence of sewage pollution, are all present in increased quantities, while the

amounts of nitrates and albuminoid ammonia assume a proper relation to the whole.

HOCKANUM RIVER.

Drainage area.—On the boundary between the towns of Tolland and Ellington, Conn., there is a lake, the level of which has been so raised by a stone embankment 35 feet high that it has an expanse of 680 acres. Its drainage area is 15.4 square miles, but in addition to the surface water which accumulates from this territory, it is largely fed by hidden springs. This lake, called Shenipsit, is the source of Hockanum River, which flows thence in a southwesterly course, emptying into Connecticut River opposite Hartford. The Hockanum is principally important by reason of the power developed along its course, for although it is less than 20 miles long it furnishes 3,957 horsepower.

Flow.—According to the measurements of General Ellis, Chief of Engineers of the U. S. Army, the flow of the river averaged 132 cubic feet per second, its maximum flow being 6,167 second-feet. The flow is peculiar by reason of the fact that about 2,000,000 cubic feet a day are allowed to run from Shenipsit Lake during working hours while no water is permitted to flow at night or on holidays.

There are several factories on the banks of the river, most of them works for the manufacture of textile fabrics and paper. Just below Shenipsit is Rockville, where 1,400 horsepower are developed.

Character of water.—Shenipsit Lake drains an area which is sparsely settled, and its water is therefore practically normal and of excellent quality. It is used as a supply for the city of Rockville and has been analyzed by the State Board of Health of Connecticut.

TABLE 58.—*Analyses of water of Shenipsit Lake.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	Samples averaged.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.				
1890–91	0.1	0.194	0.027	0.001	0.05	1.66	31.3	7	11
1900	.3	.107	.021	.000	.08	1.42	31.2	5	12

Taylor's reservoir, on the south branch of the Hockanum, is another body of normal water. It is used as a source of supply for South Manchester, Conn. Analyses made by the Connecticut State Board of Health in the year 1900 are reported as follows:

TABLE 59.—*Analyses of water from Taylor's reservoir, Manchester, Conn.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
Jan. 24	Very slight	0.4	0.130	0.028	0.001	0.10	1.7	34.5	3
Mar. 15	Clear	.1	.102	.044	.001	.05	1.5	32.0	5
May 10	do	.2	.110	.038	.002	.05	1.5	34.0	5
July 3	do	.1	.068	.022	.001	.02	1.7	35.0	3
Sept. 13	do	.1	.108	.018	.000	.03	1.6	36.5	4
Nov. 7	do	.1	.112	.112	.000	.08	2.1	37.5	3
Average		.2	.105	.025	.001	.05	1.68	34.9	4

Pollution.—The Board of Health of the State of Connecticut is investigating the character of the water in Hockanum River, samples being collected at three available points, viz, Windermere, North Manchester, and Burnside.

This work was done during the years 1895, 1896, and 1900, the samples being collected monthly, from May to October in each year. They indicate extensive pollution of this stream, but since its principal resource is water power, the damage done is not significant. The character of the water will doubtless be better in the future, by reason of the installation of a sewage purification plant in the village of South Manchester.

TABLE 60.—*Analyses of water from Hockanum River at Windermere, North Manchester, and Burnside.*

[Parts per million.]

WINDERMERE.

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.470	0.071	0.017	0.160	4.85	138.9	13
1896	.5	.913	.070	.008	.180	4.49	98.6	----
1900	.4	.910	.073	.010	.250	3.38	71.9	----

TABLE 60.—*Analyses of water from Hockanum River, etc.*—Continued.

NORTH MANCHESTER.

Year.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1895	0.5	1.096	0.124	0.008	0.110	3.87	82.1	15
1896	.5	.762	.063	.009	.160	4.45	78.3	..
1900	.3	.752	.167	.022	.240	3.95	75.4	..
BURNSIDE.								
1895	0.4	0.802	0.172	0.025	0.100	6.03	98.6	37
1896	.4	1.156	.194	.023	.140	5.61	81.4	.
1900	.4	.722	.183	.025	.160	4.65	80.7	.

PARK RIVER.

Park River is a small stream entering the Connecticut from the west. In its drainage area are the cities of New Britain and a part of Hartford. The flow is small, and, as there is a large amount of sewage brought into the river, it is probably the foulest stream in the State of Connecticut. The report of the State Board of Health made in 1895 contains the following comments:

The result of the analyses at New Britain indicate that at times during the summer the water of the stream contained as much as four-fifths of its volume of sewage. Between New Britain and section No. 2, at Newington Junction, there is practically no sewage addition. From the respective areas of the watersheds the volume of the stream at Newington should be about five times what it is at New Britain, but that the dilution must be less than this is at once apparent when it is considered that the greater part of the flow at station No. 1 is sewage and comes from other watersheds, from which the water supply is drawn. A better means of measuring dilution is by the comparison of the amounts of chlorine at the two stations, for this constituent is not removed from the stream after once having been introduced, either by precipitation or by the acts of living organisms. Since the normal chlorine of the region is about 2, there would be two parts of chlorine per million in the water of dilution added between New Britain and Newington, and, since the average amount of chlorine at the two stations is 33.1 and 15.1, respectively, it is easy to calculate that the dilution at Newington Junction is 2.4.

The average amount of nitrogen of free ammonia at New Britain was 3.04. A dilution to the extent indicated above would reduce the nitrogen of free ammonia at Newington Junction to 1.25, but the amount actually found was 2.35, a very considerable increase. This, of course, was due to putrefactive change occurring during the flow of 3¾ miles. That the changes occurring during this course were putrefactive and not oxidizing in character is shown, not alone by the increase of free

ammonia, but also by the figures for nitrites and nitrates, which show no increase, but, on the contrary, a slight relative diminution.

A similar calculation for the nitrogen of organic matter in suspension shows that there was a decrease of about 30 per cent, due, doubtless, chiefly to sedimentation. The decrease of nitrogen of organic matter in solution was somewhat more than the increase of nitrogen of free ammonia. In flowing through the course of 3¾ miles, therefore, there was some purification by sedimentation, but apparently none by oxidation, and very little by precipitation and other means. The improvement in the stream at the lower point is consequently due almost wholly to dilution with clean water from the watershed between the two stations.

Below Newington Junction there is a large increase in the flow, the relative watersheds being as 1 to 5.6. There is little direct contamination until the sewers of Hartford are reached. There are several of these in the last mile above station No. 3 in Hartford. The contamination effected by their discharge is so great that, although there is a dilution of nearly sixfold, the water in the stream at this point is about in the same condition as at Newington Junction; indeed, in respect to the organic matter the contamination is greater in Hartford.

Analyses of the water of this river were made by the Connecticut State Board of Health in the years 1895, 1897, and 1899 at New Britain, Newington, and Hartford, and the average of the results for each year are set forth in Table 61.

TABLE 61.—*Analyses of water from Pipers Brook and Park River.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as Albuminoid ammonia.	Nitrogen as Free ammonia.	Nitrogen as Nitrites.	Nitrogen as Nitrates.	Chlorine.	Total residue.	Samples analyzed.
NEW BRITAIN.								
1895	0.5	6.71	3.04	0.396	1.15	33.0	290.9	6
1897	.4	7.08	3.41	.217	1.24	26.2	271.6	6
NEWINGTON.								
1895	0.7	1.57	2.33	0.064	0.37	15.1	160.8	6
1897	.6	2.64	2.07	.064	.28	13.2	150.0	6
1899	.8	2.52	4.42	.024	.09	16.9	155.6	6
HARTFORD.								
1895	0.6	3.71	2.27	0.035	0.19	13.1	151.9	6
1897	.5	5.21	2.17	.158	.23	17.0	172.2	6
1899	.4	2.22	1.22	.208	.20	9.2	138.3	6

The pollution of Pipers Brook by the city of New Britain led to a lawsuit against the city, the final decision in which was rendered by the supreme court of errors of the first judicial district of the State of Connecticut, during the May term, at Hartford, in 1897. The suit was brought for injunction and damages before the superior court in Hartford County by Patrick Nolan, the jury giving verdict and judgment for plaintiff in $2,000 damages. The plaintiff owned a farm near Newington on Pipers Brook below the city of New Britain, upon which were dwelling houses and other buildings. The complainant stated that from October 1, 1887, to the date of complaint, the city had dumped acid, sewage, and other deleterious matter into the river and deprived him of the use of water for stock and for domestic purposes, and he had been put to a large expense thereby, his lands being injured for pasturage, his milk business having been injuriously affected, and the ice crop upon the stream having been made valueless.

The following extracts are taken from the opinion rendered by the court, the same having been handed down by Chief Justice Andrews (69 Conn., 668):

The use of Piper's Brook which the complainant charges that the defendant has made, unless there is a lawful warrant therefor, causes a public nuisance. Anything not warranted by law, which annoys or disturbs one in the use of his property, rendering its ordinary use or occupation physically uncomfortable to him, is a nuisance. (Baltimore and Ohio Railroad *v.* Fifth Baptist Church, 108 U. S., 317.) * * * The test is not the number of persons annoyed, but the possibility of annoyance to the public by the invasion of its rights. * * * (Westcott *v.* Middleton, 43 N. J. Eq., 478.) * * * That it would be a public nuisance to render the water of a stream so impure that it could not be used for domestic purposes, or for the watering of cattle, and so that it gave off noxious and unhealthy odors, is hardly open to question (Chapman *v.* Rochester, 110 N. Y., 273), for the reason that these causes would injuriously affect every riparian owner along the whole length of the stream and every person who lived near it. If a municipal corporation, in the absence of a legal right so to do, causes sewage to pollute a watercourse, to the use of which a lower owner, through whose premises the watercourse flows, is entitled, it is guilty of a nuisance for which damages may be recovered. * * * * * * The second defense depends on the act of the legislature of 1872, mentioned in the statement of the case.

* * * The said act authorizes and points out the steps to be taken in order to complete within said city a valuable public improvement, to be paid for by that species of taxation known as the assessment of damages and benefits. It empowers the common council, "whenever in their opinion the public health or sewerage shall require such action, to take, occupy, and appropriate, in such manner as they shall, from time to time, deem expedient, any stream or part of a stream, natural or artificial, running in or through said city, and to straighten, deepen, or lower the same, or lower or remove any or all walls, dams, or other obstructions to the free and healthy flow of such stream or part of a stream, or to enlarge or cause to be enlarged or lowered, any or all culverts which at any season of the year cause the accumulation of stagnant water or interrupt in any manner the free and healthy flow of any part of such stream." This is all of the act which grants power to the defendant to interfere with Piper's Brook. * * *

If it had been the intent of the legislature, by the act of 1872, to authorize the

common council of the city of New Britain to take or to affect any lands outside of the city limits, it is certain that there would have been in the act some provision for the ascertainment of damages to be paid to the landowner. The right of the plaintiff to have the water of Piper's Brook flow through his land as it has been accustomed to flow [i. e., pure and uncontaminated] "is not an easement or appurtenance, but it is inseparably annexed to the soil." (Wadsworth *v.* Tillotson, 15 Conn., 366, 373.) To deprive the plaintiff of that part of his soil for the purposes named in that act would be the taking of private property for public use, and the plaintiff would be entitled to have just compensation.

The procedure of the trial court was sustained and the award affirmed.

FARMINGTON RIVER.

Farmington River is an important stream which rises in Berkshire County, Mass., and, after a peculiar and erratic course, enters Connecticut River from the west about 5 miles above the city of Hartford. It is a notable power stream, having a fall of about 1,200 feet, a mean discharge at the mouth of the river of about 944 cubic feet per second, and a maximum discharge of nearly 25,000.

The surface of the Farmington River Basin is hilly, the uplands are well wooded, and the valleys extensively cleared for farming purposes. There are many ponds in the basin, and these, with the surface waters, maintain a fairly steady flow during the dry seasons. Indeed, it has been claimed that the development of water storage on this river has practically reached its height.

No examinations of water of the Farmington River are available. Although there are a number of thriving manufacturing villages along its course, there are no important towns in the basin; therefore pollution can not be sufficiently extensive to greatly damage the river.

CONNECTICUT RIVER.

Analyses of the water of Connecticut River at Northfield Farms, in the northern part of Massachusetts, just below the State line, show that the pollution which enters from the States of Vermont and New Hampshire has very little effect on the apparent composition of the water. Indeed, such is the dilution of the sewage poured into the river north of the Massachusetts line that the chlorine in the water at Northfield is nearly normal. In the Connecticut Valley in New Hampshire and Vermont there are only a few important towns, and these are probably not completely sewered, if at all. Brattleboro and Bellows Falls in Vermont, with populations of 5,297 and 4,377, respectively, are the only places in that State from which there is likely to arise any appreciable pollution. In New Hampshire, the city of Keene drains into the Connecticut by way of the Ashuelot, and the town of Claremont is situated directly upon the river. These places have populations of 9,165 and 6,498, respectively.

TABLE 62.—*Analyses of water from Connecticut River at Northfield Farms.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 18	Slight	2.8	0.156	0.012	0.001	0.000	0.6	60.5	30
August 20	Very slight	3.0	.142	.006	.003	.040	.8	60.5	33
September 17	do	2.4	.114	.006	.000	.010	1.1	71.0	38
October 15	do	8.3	.270	.045	.000	.050	.8	62.5	22
November 19	Slight	6.8	.270	.044	.001	.050	1.0	57.5	21
December 17	Very slight	2.4	.148	.024	.006	.190	1.1	60.5	30
Average		4.3	.183	.023	.002	.057	.9	62.1	29

The available analyses of the river's water next below Northfield Farms were made at Turners Falls, in the town of Montague, from 1887 to 1889. Although, under ordinary circumstances, a series of analyses made at such an early date would not be applicable to the present conditions, the changes in the population above this point have not been sufficient to materially alter the condition of the river. The average of 21 analyses is set forth in Table 63.

TABLE 63.—*Average of twenty-one analyses of water from Connecticut River at Turners Falls.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
Slight	3.0	0.140	0.025	0.003	0.123	1.0	63.8

The report of the Massachusetts State Board of Health for 1899 gives a significant analysis of the water of the Connecticut River opposite Northampton as follows:

TABLE 64.—*Analysis of water from Connecticut River at Northampton.*

[Parts per million.]

Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
Very slight	3.0	0.232	0.018	0.001	0.030	0.9	57.5	26

Continuing downstream we find that the next available analyses are those made by the State Board of Health of water taken from Connecticut River at a point below Springfield. Here are the first prominent indications of pollution shown by analytical methods. Above this point there are Chicopee, Westfield, and Millers rivers, which are, as has been already stated, in a polluted condition. On the main river there are the cities of Northampton, Springfield, and Holyoke, as well as smaller towns, all of which contribute a large measure of pollution. It is not surprising then, that by the time the river reaches this point below Springfield it should betray by chemical analyses the abuse which it has suffered.

TABLE 65.—*Analysis of water from Connecticut River below Springfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
July 17	Very slight	2.5	0.181	0.112	0.002	0.010	1.7	61.0	34
August 18	Slight	2.4	.148	.112	.002	.020	1.6	61.5	34
September 18	Decided	2.9	.280	.156	.004	.040	2.9	78.5	36
October 18	Very slight	7.1	.268	.064	.002	.020	1.7	66.0	25
November 21	Decided	7.2	.368	.048	.002	.080	2.0	65.0	27
December 29	Slight	2.6	.152	.006	.001	.090	1.8	49.0	25
Average		4.1	.233	.083	.002	.043	1.9	63.5	30

Crossing over into the State of Connecticut, the river receives other and extensive pollution. The Farmington, Hockanum, Salmon, and other tributaries have already been discussed. On the main river are Hartford and Middletown, as well as numerous other smaller centers, which materially increase the amount of pollution. In the years 1890, 1893, 1894, and 1899, the State Board of Health of Connecticut made examinations of the water of the river at three points, viz: Warehouse Point, Rocky Hill, and Goodspeed Landing. Analyses made at these points are well adapted to show the effects of the contribution by various towns of new contamination to the already polluted river.

TABLE 66.—*Analyses of water from Connecticut River at Warehouse Point, Rocky Hill, and Goodspeed Landing.*

[Parts per million.]

Year.	Color.	Nitrogen as-				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
WAREHOUSE POINT.								
1890–91	3	0.126	0.034	0.002	0.12	1.23	44.2	23
1893	3	.116	.086	"much"	.20	1.85	66.5	...
1894	3	.192	.064	.005	.06	2.58	76.5	44
1899	2	.130	.048	.002	.15	2.70	77.5	30
ROCKY HILL.								
1890–91	3	0.135	0.033	0.002	0.11	1.28	44.6	25
1893	3	.112	.054	.010	.10	1.75	66.5	...
1894	3	.156	.102	.006	.30	3.50	73.5	48
1899	3	.164	.068	.008	.18	2.70	73.5	32
GOODSPEED LANDING.								
1890–91	3	0.130	0.036	0.001	0.13	1.36	45.0	25
1893	3	.110	.044	.005	.08	1.81	65.5	...
1894	2	.182	.064	.004	.08	3.04	73.0	44
1899	3	.244	.066	.008	.20	3.20	73.0	32

There is little to add concerning the Connecticut River and its relations to the various interests which have claims upon it. There is no reason why this stream could not be kept in a condition that would be acceptable to all concerned. Under the present conditions, however, much of its value is lost. The river comes down to the Massachusetts line practically uninjured, but in its course through Massachusetts it is robbed of its values as a source of water supply and of ice. Under the present policy of the State authorities the condition of the river is not likely to grow worse, but, on the contrary, will no doubt be improved, so that we can look forward with confidence to the removal of the dangerous wastes which are now poured into the Connecticut system in Massachusetts. In Connecticut the river has great values as a source of power, as a means of navigation, and as a park nucleus, but the remainder of its normal values have been destroyed.

HOUSATONIC RIVER.

NATURAL RESOURCES.

Course.—The Housatonic is an important stream flowing through the extreme southwestern part of New England. It has its origin in the central part of Berkshire County, Mass., being formed by the confluence of East and West branches, which unite at Pittsfield. From Pittsfield it flows southward in a somewhat tortuous course, passing into Connecticut through Litchfield County, and still farther south forming the boundary between New Haven and Fairfield counties, finally emptying into Long Island Sound near Bridgeport. (See fig. 11.)

Drainage basin.—The area drained by Housatonic River comprises 1,933 square miles, of which 503 are in Massachusetts. The river in its winding course traverses about 125 miles. The East Branch, which has a drainage area of 70 square miles, rises not far from Pittsfield, and flows by an extremely circuitous route through the manufacturing settlements of Hinsdale and Dalton, finally joining West Branch south of Pittsfield. The West Branch is formed by the overflow of Onota and Pontoosuc lakes, in Pittsfield, and flows in a southerly direction, draining an area of 59 square miles. One of the principal branches of West Branch is Southwest Branch, which rises in Richmond Lake and joins West Branch a short distance above its confluence with East Branch.

Fall.—The fall of the river between Pittsfield and Long Island Sound amounts to about 1,000 feet. It is distributed along gravelly shoals, with intervening stretches of quiet water. There are falls at New Milford, Bulls Bridge, and Falls Village.

TABLE 67.—*Table showing fall in Housatonic River.*

Locality.	Distance above mouth.	Elevation above mouth.	Fall between points.	Distance between points.	Average fall per mile between points.
	Miles.	*Feet.*	*Feet.*	*Miles.*	*Feet.*
Pittsfield, Mass	123	983			
Ashley Falls, Mass	81½	705	361	50.5	7.15
Falls Village, Conn	72½	622			
1.8 miles above Cornwall Bridge			165	8.5	19.41
	64	457	352	43.5	10.20
Mouth of Shepaug River	29½	105			
Birmingham	11		105	18.5	5.68

The drainage area is hilly and even mountainous, the uplands are fairly well wooded, and the valleys are wide, with alluvial meadows. The falls in the river are over ledges of limestone and granite, and fairly good building marble is quarried. A small amount of iron ore is mined. There is also easily available a pure quartz sand which has become famous in the glass industry.

The country is prosperous, and the power facilities have attracted a skilled class of artisans. The principal industries are the manufacture of paper and woolen goods. The railroad facilities are very good.

Flow.—The flow of the river is fairly steady, because of the large storage area, which is partly natural and partly of artificial development. It is probable that the reservoir capacity has been developed to nearly its full extent. The approximate area of 35 ponds and reservoirs in the basin is 9,304 acres.

The principal ponds are Pontoosic Lake, Lanesboro, Mass., 313 acres; Onota Lake, Litchfield, Mass., 555 acres; Ashmere reservoir, Hinsdale, Mass., 310 acres; Washince Lake, Salisbury, Conn., 400 acres; Washining Lake, Salisbury, Conn., 650 acres; Wononscopomus Lake, Salisbury, Conn., 355 acres; Quassapaug Pond, Middlebury, Conn., 535 acres; Bantam Lake, Litchfield, Conn., 1,070 acres; North Pond, Goshen, Conn., 300 acres.

There have been no gagings of the river extending over a period

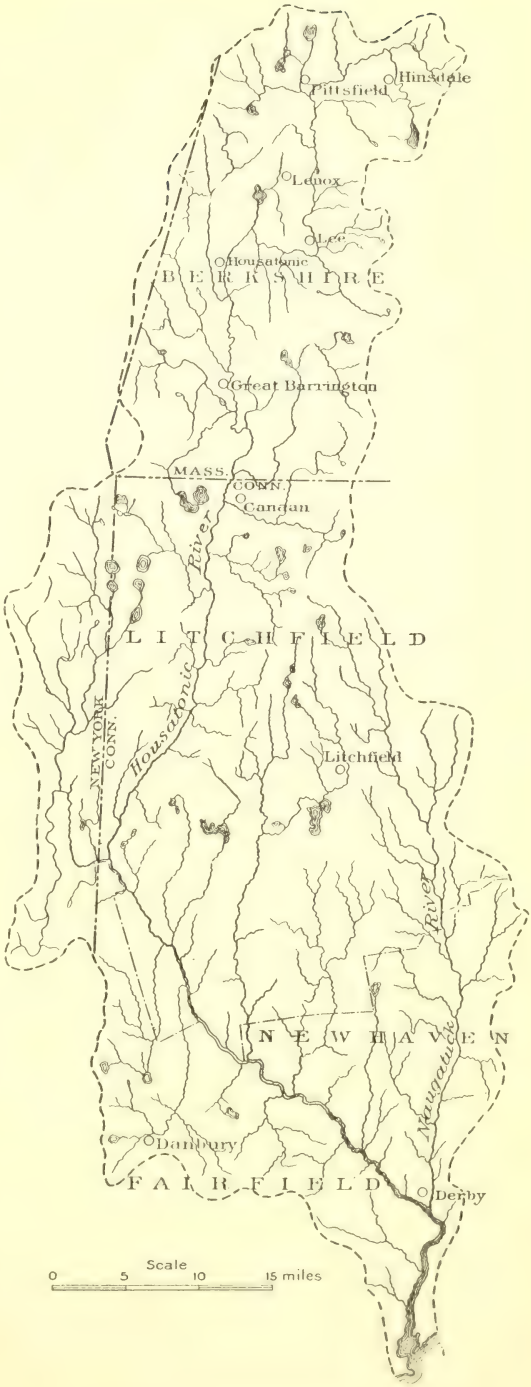

FIG. 11.—Housatonic River drainage basin.

sufficiently long to determine its flow with accuracy. In the year 1878 careful examinations were made from May to November at Kent, by the water department of New York, and the results probably show fairly well the summer flow of the river. According to these gagings the minimum flow for twenty-four hours was 260 cubic feet per second, while the average flow for the same period amounted to 460 cubic feet per second.

Water power.—After what has already been stated it is hardly necessary to say that the river may be valuable as a source of power. The total utilized horsepower on the whole system is about 18,884. In the main river the utilized horsepower is 6,434, and the remainder is distributed among the tributaries as follows: Naugatuck River, 4,909; Mad River, 1,220; Pomperaug River, 361; Shepaug River, 695; all other tributaries, 5,265.

The details of the power system are well set forth in the Tenth Census Report on Water Power, Vol. XVI.

NORMAL WATER IN THE HOUSATONIC BASIN.

The limestone formations in the Housatonic Basin make the water hard. In other respects the normal Housatonic water does not materially differ from that in the Connecticut Basin. The normal chlorine for this region varies from about 0.8 part per million at the upper end of the area to 3 parts near the mouth of the river.

The following table of analyses represents the averages of the results of various examinations of water made during the past decade.

TABLE 68.—*Analyses of various normal waters in the Housatonic drainage area.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
East Branch of Housatonic above Hinsdale.	Slight	2.0	0.138	0.036	0.001	0.180	0.8	54.0	----
Lake Oneota, Pittsfield	Very slight	9	.158	.000	.000	.030	.3	66.0	----
Pontoosuc Lake, Pittsfield.	do	0	.128	.006	.000	.000	.4	79.0	----
Egypt Brook, Dalton	do	2.9	.080	.002	.000	.196	.7	27.3	----
Green River, Great Barrington.	do	------	.028	.005	.000	.225	1.0	74.1	56
Hinsdale storage reservoir.	do	2.1	.202	.017	.000	.017	.7	20.7	1
Upper reservoir, Berkshire Water Co.	do	3.9	.303	.056	.000	.027	1.0	26.7	4
Millbrook reservoir, Pittsfield.	do	.1	.095	.011	.000	.057	.9	53.5	40
Lake Averic, Stockbridge.	do	.8	.181	.021	.000	.022	.8	62.0	40
Padaranium reservoir, Danbury.	do	.3	.162	.030	.003	.09	1.95	47.7	13
Kent reservoir	do	.1	.080	.008	.000	.12	1.56	64.5	30
North Canaan	do	.02	.030	.004	.001	.05	1.25	111.6	93
Farm Brook	do	.4	.105	.022	.001	.11	1.84	50.2	12

POLLUTION IN THE HOUSATONIC.

The population in the Housatonic Basin has increased rapidly during recent years, and the consequent pollution has become a matter of grave consideration.

The East Branch of the Housatonic receives pollution from the manufacturing villages of Hinsdale and Dalton, which have a population of 1,485 and 3,014, respectively. The report of the State Board of Health for 1890 gives analyses of water collected below these villages which show a considerable increase in the amount of organic matter present. A comparison of the analyses in Table 69 with the first analysis presented in Table 68 will clearly show indications of sewage pollution.

TABLE 69.—*Analyses of water from East Branch of the Housatonic above Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.		
1888.								
Sept. 7	Slight	2.0	0.238	0.092	0.008	0.180	1.9	112
Do	Distinct	2.0	.390	.092	.003	.200	2.0	117.5

Although these analyses were made in the year 1888, the conditions now existing in the river compare very closely to those found in the year of the analyses. The population in this part of the drainage area has not increased materially and the analyses therefore fairly represent existing conditions.

TABLE 70.—*Analyses of water from the East Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	2.4	0.264	0.192	0.004	0.100	1.4	92.5	56
July 27	Decided	2.2	.416	.128	.006	.070	2.6	101.5	70
September 14	do	2.4	.244	.100	.009	.060	3.1	122.5	87
September 25	Very slight	2.2	.412	.168	.007	.100	3.0	126.5	91
October 23	Slight	3.0	.464	.196	.008	.120	3.9	135.5	97
November 20	Decided	4.0	.416	.060	.002	.190	2.4	98.5	63
December 18	Slight	2.1	.324	.106	.006	.310	2.3	106.5	79
Average		2.7	.369	.136	.006	.145	2.6	109.5	76

TABLE 71.—*Analyses of water from West Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	1.5	0.268	0.084	0.001	0.010	1.5	76.5	46
July 27	do	.8	.216	.004	.000	.000	2.4	83.5	53
September 14	Decided	1.5	.432	.008	.000	.020	2.8	92.5	63
September 25	do	2.0	.452	.012	.002	.010	3.2	104.0	63
October 23	do		3.260	.970	.000	.010	15.6	458.0	89
November 20	do	2.1	.410	.080	.003	.060	2.2	102.0	60
December 18	do	.8	.328	.140	.019	.090	1.8	103.5	79
Average		1.4	.821	.209	.031	.031	4.4	155.3	65

TABLE 72.—*Analyses of water from Southwest Branch of the Housatonic at Pittsfield.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
June 26	Slight	0.9	0.376	0.372	0.016	0.040	2.3	96.5	61
July 27	do	1.4	.210	.100	.004	.060	1.2	137.5	103
September 14	Decided	1.3	.434	.064	.012	.020	1.8	154.0	96
September 25	do	1.2	.440	.092	.005	.010	2.5	144.0	94
October 23	do	1.5	.364	.304	.007	.080	2.6	180.5	123
November 20	do	2.0	.284	.180	.006	.340	2.3	180.0	126
December 18	None	.8	.072	.036	.002	.420	1.8	116.5	97
Average		1.3	.291	.166	.007	.159	2.0	144.3	101

The analyses set forth in Tables 70, 71, and 72 represent the character of the water furnished to the Housatonic River. It will be seen that every branch which contributes to form the main artery at Pittsfield is highly polluted, and therefore the Housatonic at the very outset is a badly damaged stream. The West Branch seems to be in the foulest condition, the East Branch closely following. Nearly all

the pollution in the West and Southwest branches is furnished by the city of Pittsfield. The upper reaches of these two streams remain in excellent condition.

Pittsfield, a city of 21,766 inhabitants, has a public water supply and a system of sewerage which empties into the three branches of the river. During the period in which the analyses in Tables 70, 71, and 72 were made a sewage-purification system for the city of Pittsfield was in course of construction, and when this is put into operation a large part of the sewage which now enters the river will be no longer a source of pollution.

Passing down the river we find that the next available analyses of Housatonic River water were made from samples taken at New Lenox, a point about 4 miles below Pittsfield. The drainage area of the river at this point is 145.6 square miles, the population being about 177 per square mile. The following table comprises the average result of monthly examinations of the water at this point since the year 1894:

TABLE 73.—*Analyses of water from Housatonic River at New Lenox.*

[Parts per million.]

Year.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1894	2.7	0.183	0.131	0.024	0.204	2.5	131.7	85
1895	2.6	.238	.183	.038	.173	2.5	117.3	84
1896	2.6	.192	.169	.036	.208	2.2	118.8	86
1897	3.2	.240	.159	.008	.203	1.9	107.9	75
1898	2.7	.223	.106	.008	.178	1.5	94.0	64
1899	2.0	.233	.197	.017	.132	2.3	107.6	74
1900	2.2	.278	.378	.018	.118	2.8	111.7	72

Comparison of Table 73 with the three preceding tables shows that very little change has taken place in the amount and character of the organic matter in the river after it has traversed the 4 miles above mentioned. The water seems to be fairly loaded with polluting material in every state of oxidation, and there seems to be extremely rapid decomposition going on. There is nothing of an unusual nature in the above series. They present and clearly indicate an abundant pollution, which, as we have seen, is borne out by facts.

Leaving New Lenox the river flows south past the town of Lenox, which has a population of 2,942. At this place there is a sewerage system, but it is provided with a disposal plant, so that the river does not receive a large increment of pollution. A few miles farther down

the river runs through the town of Lee, which contains 3,956 inhabitants. Considerable polluting matter is poured in at this point. Shortly below Lee the river makes a sharp turn eastward and flows through Stockbridge, a town which has a population of 2,031. A sewerage system is maintained at this point and filter beds have been provided, so that extensive pollution of the river is avoided.

TABLE 74.—*Analyses of water from Housatonic River at Stockbridge.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.
1900.									
June 26	Very slight	1.1	0.312	0.284	0.016	0.070	2.9	120.5	96
July 31	do	.8	.198	.174	.014	.100	2.6	171.0	83
August 27	Decided	1.5	.240	.208	.026	.022	3.3	136.0	93
September 26	Very slight	1.2	.192	.072	.012	.110	3.9	135.0	103
October 23	do	1.5	.236	.228	.018	.220	4.4	166.5	117
November 21	Decided	3.5	.380	.208	.007	.210	3.7	123.5	86
Average		1.6	.260	.195	.005	.152	3.5	133.1	96

After leaving Stockbridge the river again turns south and flows through the town of Great Barrington which has a population of 5,854 and which contributes a large amount of pollution.

The next series of analyses made by the Massachusetts State Board of Health is of the water from the river at Sheffield, just north of the Connecticut State line. There seems to be considerable improvement in the water at this point over that at Stockbridge. The average of the six analyses of the water from the river made during the year 1900 is set forth in the following table:

TABLE 75.—*Average of six analyses of water from Housatonic River at Sheffield.*

[Parts per million.]

Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness.	Number of samples.
1.6	0.214	0.079	0.004	1.93	2.8	128.2	90	6

The above average of analyses clearly indicates a fairly large degree of purification over that shown in Table 74. It will be seen that while the color and residue are practically the same, the free and albuminoid ammonia and the nitrites are considerably less, while the nitrates are higher—an unmistakable indication of oxidation. The chlorine, too, seems to be in smaller proportion, the river having been largely diluted by the influx of pure water.

Passing over into the State of Connecticut the Housatonic runs by or through the towns of Salisbury and North Canaan, where the population is almost entirely rural, although these places are rather thickly settled.

At Falls Village, a few miles south of the Massachusetts border, the Board of Health of the State of Connecticut has during the year 1900 been securing samples of water for analysis the results of which are set forth in the following table:

TABLE 76.—*Analyses of water from Housatonic River at Falls Village, Conn.*

[Parts per million.]

Date of examination.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.									
January 26	Slight	0.3	0.192	0.044	0.002	0.15	1.7	79.0	60
February 22	Distinct	.2	.102	.042	.002	.10	1.9	86.0	70
March 21	Very slight	.3	.170	.018	.004	.15	1.6	69.0	35
April 30	None	.2	.082	.046	.002	.05	1.8	67.0	75
May 17	Slight	.3	.188	.070	.008	.05	2.0	62.5	60
June 11	do	.2	.174	.090	.001	.10	2.1	111.0	90
July 5	None	.2	.112	.028	.003	.10	2.7	125.0	70
August 14	Slight	.1	.118	.024	.002	.18	2.9	131.0	63
September 12	do	.3	.207	.026	.004	.13	2.1	115.0	55
October 10	do	.2	.100	.020	.002	.13	4.0	145.5	68
November 13	do	.4	.148	.012	.002	.22	3.3	139.5	53
December 10	do	.4	.146	.034	.006	.20	1.6	106.0	59
Average		.3	.150	.038	.003	.13	2.3	103.0	63

Comparison of the above series with that made of the water at Sheffield, Mass., shows a still further purification. In some respects the water at Falls Village is considerably better than at any point since it received its first contamination at Pittsfield. One can not fail to be impressed with the fact that the Housatonic has excellent

powers of recovery, and it is very likely that if the sewage of the various towns along its banks is submitted to proper treatment the river will approach nearly its normal purity.

The State Board of Health of Connecticut has conducted another series of analyses of the water at a point 65 miles below the town of Falls Village, at the town of Derby, just below where the Naugatuck joins the river. In passing from Falls Village to Derby the Housatonic goes by the towns of Sharon, Cornwall, Kent, New Milford, Bridgewater, Brookfield, Roxbury, Southbury, Oxford, Newton, Monroe, Seymour, and Huntington. All these municipalities contain from 1,000 to 3,000 inhabitants, and contribute an amount of contaminations usual in such cases. In addition to these towns there is the city of Danbury, with a population of 16,000, which contributes raw sewage in large amount. In spite of this additional pollution, however, the analysis made at Derby shows very little change in the character of the water.

TABLE 77.—*Analyses of water from Housatonic River at Derby.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1900.								
January 29	0.3	0.122	0.052	0.002	0.10	2.3	79.0	60
February 24	.3	.108	.040	.002	.10	2.1	60.0	40
March 24	.3	.128	.050	.040	.15	1.9	51.5	27
April 26	.3	.124	.036	.002	.05	2.3	75.5	45
May 17	.3	.108	.060	.006	.15	1.9	80.5	70
June 11	.3	.100	.078	.002	.15	2.3	99.0	80
July 5	.2	.144	.050	.002	.05	2.4	108.5	70
August 24	.2	.140	.040	.000	.10	2.3	115.5	57
September 11	.2	.144	.026	.060	.05	2.8	116.5	91
October 10	.1	.144	.036	.001	.10	3.6	116.0	58
November 4	.5	.188	.016	.004	.19	3.5	113.5	36
December 10	.4	.168	.006	.006	.20	1.9	82.5	43
Average	.3	.136	.042	.008	.13	2.44	91.5	56

Below Derby the Housatonic receives the polluted water of its principal tributary, the Naugatuck, and flows thence into Long Island Sound. We have now traced the river from its source in Massachusetts to its mouth, and have found that from its headwaters it is

polluted to a sufficient extent to entirely unfit it for a source of water supply unless the water is filtered. This, however, is about as far as damage extends. Although considerable sewage enters the river at different points, such is the dilution and such the purifying capacity that it does not, except at a few points, betray its contamination, except by chemical analyses. As it crosses from Massachusetts into Connecticut it is in a condition which makes its use by the people of Connecticut as a source of water supply impossible without filtration. It is probable that the Housatonic River will in the future be constantly improved by the removal of sewage contamination through the establishment of purification works at the various points of pollution.

COURT DECISIONS IN CONNECTICUT.

The opinion of the supreme court of errors of the State of Connecticut in a suit at law against the city of New Britain, arising from the pollution of a watercourse, has already been cited. The courts of Connecticut have taken no uncertain stand on the question of river pollution. In no other State in the Union has there been such unequivocal judicial disapproval of the practice of destroying water resources, and as future work along this line will probably result in frequent reference to the Connecticut cases it seems wise to review briefly the different decisions which have been rendered.

The case of Morgan *v.* The City of Danbury is of interest, inasmuch as it involves a decision against a city which had provided a purification plant for the disposal of sewage. The plaintiff, a riparian owner and a mill proprietor on Still River, complained in the superior court that the defendant, without making him any compensation or attempting to acquire any of his rights, did discharge and was continuing to discharge into that river wastes, sewage, and other noxious substances, and prayed for an injunction against the continuance of that practice.

Danbury is a city of 20,000 inhabitants, situated on Still River, a small sluggish stream which empties into the Housatonic 16 miles below. In 1885 a system of sewerage was constructed which emptied directly into Still River. By the year 1890 the use of the sewers had increased to such an extent as to cause a local nuisance. In 1893 an outfall sewer was completed which conducted the sewage 1 mile below the city. During the summer seasons Still River has scarcely any flow, and the Woolf disinfecting system was installed in 1894, for use during the dry stages of the river. It consisted of large vats of brine, from which a solution known as hyperchloride of sodium was developed by electric currents.

An injunction was granted against further discharge of sewage. An appeal was taken.

The case was reviewed by the supreme court of errors in the January term in the third judicial district, 1896, and following are

extracts of the opinion of the court handed down by Associate Justice Baldwin (67 Conn., 484):

The complaint alleged that the city was discharging waste matter, sewage, and other noxious, corrupt, and impure substances from its sewers so as to pollute the river and to cause much of such discharges to be deposited on the plaintiff's land and mill privilege; and that thereby he had been largely deprived of the use of a valuable mill and mill privilege, he and his workmen injuriously exposed to noxious odors, the air in the neighborhood corrupted and poisoned so as to endanger the health of himself and others, his milldam partly filled up with filth, the value of his property greatly diminished, and he disabled from disposing of his land for building purposes. * * *

These allegations were denied, but have been found true; and there is nothing inconsistent with their truth in the special finding of facts. * * * It was proper that an injunction should be so framed as to protect the plaintiff against every serious and irreparable injury which he might suffer by the continuance of the nuisance, and its terms are fully conformable to the claims stated in his complaint.

* * * The supplemental answer, setting up the establishment of the Woolf disinfecting plant, avers that the discharges from the sewer have thereby been rendered "entirely harmless and free from any offensive qualities, and no solid matter is permitted to empty from said sewer into said stream, but the same is liquefied and clarified and the plaintiff is relieved thereby of all danger in the future from the said sewer." * * * These allegations were denied, and the issues upon them have been found for the plaintiff.

* * * It is not impossible that fluids discharged from the sewer, although colorless, sterilized, and apparently innoxious, may yet be such as, by combination with other substances found in the river, to become the occasion of decomposition and consequent pollution. * * *

The defendant urges that it should not be made responsible for the acts of others, and that if its sewage is thoroughly disinfected, sterilized, and purified before its discharge into the river, nothing further should be required, even though, as it flows down the stream, it may be brought into contact with other substances in such a way as to work a nuisance. But the right to deposit a thing in any place must always be dependent, not only on its own nature but on the nature of the place in question and the uses to which that has already been put.

In a similar suit brought by Platt Bros. & Co., to restrain the city of Waterbury from polluting Naugatuck River above the complainant's mill, the superior court rendered judgment for $500, and an injunction was issued. Appeal was made by the State to the supreme court of errors, and a decision was handed down January 4, 1900, by Associate Justice Hammersley. This opinion deals so clearly and admirably with that oft-repeated contention of municipal authorities that a city is not liable for damages because of sewage, if it has been authorized to turn the same into a stream by an act of the legislature, that a large part of the decision will be given here (72 Conn., 531):

The main contention of the defendant may be stated in this way: The use of the sewers, under authority of the legislature, in the manner described, is a public, governmental use; the injuries to the plaintiffs result from this governmental use and are not direct but merely consequential; the victim of consequential injuries resulting from a governmental use is entitled to no remedy unless one is given by statute; the defendant's charter provides no remedy for consequential injuries

resulting from the use of said sewers; ergo, the plaintiff has no remedy, and its damage is damnum absque injuria.

The premises essential to this conclusion are untrue. A governmental use may include any act which the State may lawfully perform or authorize. There are, however, governmental acts to which certain immunities attach; and it is with this restricted meaning that the phrase is used by the defendant. In this sense a governmental act is one done in pursuance of some duty imposed by the State on a person, individual or corporate, which duty is one pertaining to the administration of government, and is imposed as an absolute obligation on a person who receives no profit or advantage peculiar to himself from its execution. It is the State, exercising its governmental power through an agent who, in this matter, is the agent of the State and nothing more. It is to be distinguished from a large class of governmental acts which the State, by way of grant or special privilege, authorizes persons to perform in part for their personal benefit. The principal immunities belonging to a governmental act, in this restricted sense, are: (1) Freedom from personal responsibility for the consequences of the act done. So long as a lawful mandate of the State is faithfully executed, the agent acting within the scope of that authority enjoys the exemption from suit which belongs the State. (2) Freedom from personal responsibility for the negligence of his servants. The rule of respondeat superior does not apply, because the agent of the State is not the superior; the real superior is the State itself.

The defendant claims these immunities. It may be doubted whether the use of sewers under the charter of the defendant, for the collection and disposition of refuse belonging to its citizens, is a governmental act within the definition given. The charter authorized the construction of sewers for that purpose, but no absolute duty was imposed upon the city; action in pursuance of the authority was at its option and could not have been enforced by any process of law without further legislation. While sewers or drains for the disposition of surface waters collecting in highways may be considered as mere adjuncts of a highway, partaking of its nature as a governmental use (Cone *v.* Hartford, 28 Conn., 363, 372), it is different with sewers for the disposition of refuse and filth accumulated upon private property. The disposition of such stuff is in part for the benefit of the property holder. The city represents, in such respects, the interests of its inhabitants, and is granted certain special powers, in part for the promotion of their interests (Bronson *v.* Wallingford, 54 Conn., 513, 519). It is well settled that there is a clear distinction between those governmental duties imposed upon a city as a mere agent of government and those governmental powers granted as a privilege primarily for the personal benefit of its inhabitants. * * * We think it evident that the mere granting authority to a city to construct, for the convenience and benefit of its inhabitants, sewers adapted to carry off their refuse matter to some neighboring stream, does not necessarily make such use of the sewers a governmental use in the sense indicated. * * *

But if, for the purpose of this case, we concede the defendant's claim that the use is a governmental use, it is nevertheless liable to the plaintiff. The injury described by the complaint is not a mere consequential damage, like that resulting wholly from the lawful use of one's own property, or the lawful exercise of governmental power; it is a direct appropriation of well recognized property rights within the guarantee of the Constitution—"The property of no person shall be taken for public use without just compensation therefor" (Nolan *v.* New Britain, supra, p. 81), and so the defendant's claim that its charter does not authorize the condemnation of the plaintiff's property rights is immaterial. Upon a careful examination of the charter as enacted in 1871 (7 Special Acts, 206) and amended in 1881 (9 id., 233 et seq., 237), in 1883 (9 id., 839), and in 1884 (9 id., 954), and applying the rule which requires a law to be so construed, if reasonably possible, as to

give it validity, we think the city is authorized to make compensation by agreement or after appraisal, for any private property taken for the purpose of the maintenance and use of the sewers authorized. But if it were otherwise, the defendant would not be benefited. Its whole defense of acting under lawful State authority would then fail, and the mere finding of the facts alleged in the complaint would clearly support the judgment.

The defendant's brief presents its claim in a form somewhat different from that stated in the finding, and certainly novel in this State. It is substantially this: (1) A riparian city has a right to use the river for certain drainage, and such surface drainage necessarily pollutes the water to some extent, increasing with the growth of the city. (2) The use of these legitimate drains to carry off the noxious refuse accumulated by its inhabitants becomes in time an absolute necessity. (3) The right of surface drainage is thereby enlarged so as to include the right to discharge into the river, by means of these drains, such noxious refuse. Therefore the necessities of municipal growth give the city a right to convey these noxious substances to the property of downstream proprietors, and so to appropriate that property for public use without compensation.

It is unnecessary now to discuss the limitations to the right of surface drainage, for the second and third propositions are clearly wrong. The right to pour into the river surface drainage does not include the right to mix with that drainage noxious substances in such quantities that the river can not dilute them nor safely carry them off without injury to the property of others. The latter act is, in effect, an appropriation of the bed of the river as an open sewer, and the proposition that it may become lawful by reason of necessity is inconsistent with undoubted axioms of jurisprudence. The appropriation of the river to carry such substances to the property of another is an invasion of his right of property. When done for a private purpose it is an unjustifiable wrong. When done for a public purpose it may become justifiable, but only upon payment of compensation for the property thus taken. Public necessity may justify the taking, but can not justify the taking without compensation. It may be necessary for a city to thus mix with its drainage such substances, but it is not necessary to pour such mixture into the river without purification; indeed, the purification is coming to be recognized as a necessity. But however great the necessity may be, it can have no effect on the right to compensation for property taken. The mandate of the Constitution is intended to express a universally accepted principle of justice, and should receive a construction in accordance with that principle, broad enough to enable the court to protect every person in the rights of property thus secured by fundamental law.

There are certain apparent, but not real, exceptions to this protection. Emergencies may be such as to justify the taking of property without waiting to provide for compensation; property may be destroyed without compensation in certain cases when used unlawfully, or when it has become a thing of danger. But this is not a case of war or conflagration. The plaintiff has not so used its property as to subject it to the harsh police power of confiscation. The plaintiff has certain rights as a riparian landowner. These rights are property within the meaning of our constitutional guaranty, and an invasion of these rights such as the defendant has made is a taking of that property. The legislature has no power to authorize such taking except for public use, and then only upon providing for just compensation. (Kellogg *v.* New Britain, 62 Conn., 232, 239; Wadsworth *v.* Tillotson, 15 id., 366, 373; Harding *v.* Stamford Water Co., 41 id., 87, 93; Nolan *v.* New Britain, 69 id., 668, 681; Fisk *v.* Hartford, 70 Conn., 720, 731; Seifert *v.* Brooklyn, 101 N. Y., 136; Chapman *v.* Rochester, 110 id., 273, 277.)

An action for fouling a brook and mill privilege by the discharge of sewage, with a claim for damages and an injunction against the town of New Milford, was brought by Joseph E. Watson et ux. in the

superior court in Litchfield County, and on trial by the court (Shumway, J.) an injunction was refused and judgment was rendered for the plaintiff for $50 damages. An appeal was taken by the defendant for alleged errors in the rulings of the court. No error.

The finding stated these facts:

The plaintiffs' land is situated on Great Brook, in New Milford. There are no buildings on it. To use it for buildings would require some previous filling on a part of it. It has been used for pasturage, and partly for cultivation, but yields now little income. The annual rental value is $75, and has not been substantially affected by the fouling of the brook. The court, at the request of the parties, viewed the premises, in the summer, when the water was low, and saw on the margin of the brook a sediment giving off odors of putrefying sewage, unwholesome and offensive, and also undissolved constituents of house sewage lying on the ground, offensive to the sight. At times of high water such conditions would not exist.

Since 1876 the sewage from the town hall had been discharged through a drain constructed by a village improvement association into Great Brook above the plaintiffs' land. In 1893 all the school districts in the town were consolidated, and the town took charge of the public schoolhouses then erected. One of these then discharged its sewage into Great Brook, and has ever since.

The plaintiffs lived seven miles from their land in question. The waters of the brook, where it runs through it, are potable by cattle, and there are trout in it. This water privilege has no value in its present condition.

In 1893 the defendant extended certain sewers through the plaintiffs' land and into the brook thereon, and has since maintained the same. These serve to carry off the surface water from the streets, and also house sewage. Various houses have been connected with them for the discharge of their sewage into them, with the knowledge of the selectmen.

The town, by its use of the brook as a means of getting rid of the sewage from the town hall and schoolhouse, has, in connection with its use by citizens for carrying off sewage from their houses, caused the state of things viewed by the court. The damage thus caused is not irreparable, but an injunction would be a proper remedy to prevent multiplicity of suits, should the town continue such use of the plaintiffs' premises for an unreasonable length of time hereafter. It was not found that the nuisance had prevented them from effecting a sale of the property.

The case was reviewed by the supreme court of errors in the January term, in the first judicial district, 1900, and the following extracts from the decision handed down January 19, 1900, by Associate Justice Baldwin (72 Conn., 561):

A nuisance was created upon the plaintiffs' land by the deposit of sewage and sediment from sewage, offensive from its appearance or its smell. The use of the sewers which receive the surface drainage from highways, and of that built by the village improvement association, by the defendant, to carry off the sewage from its public buildings, contributed to this injury. That others also contributed to it, and perhaps more largely, did not relieve the town from liability. (Morgan *v.* Danbury, 67 Conn., 484, 496.)

That the plaintiffs suffered no personal inconvenience from the nuisance, because they did not reside in the vicinity, is immaterial. They were entitled to nominal damages, at least, for the offensive condition of things upon their land, even if they never visited it, and although its rental and selling value remained unimpaired. (Watson *v.* New Milford Water Co., 71 Conn., 442.) If those assessed

can be regarded as substantial, they are still so small in amount that no new trial should be granted for their reduction. (Buddington *v.* Knowles, 30 Conn., 26; Holbrook *v.* Bentley, 32 id., 502, 508.)

The action was well brought against the defendant as a town, and not as a consolidated school district. It is a single corporation, and the consolidation simply threw upon it additional powers and duties. It maintained as a town a nuisance previously created by a district.

That the plaintiffs in prior years had discharged sewage and dyes from a hat shop on their premises into the brook did not bar their right of recovery. If they had thus fouled the brook to the injury of landowners below them, it did not operate as a license to landowners above them to use it in a similar way.

That the water remained potable by cattle and inhabitable by fish was unimportant except in mitigation of damages.

DELAWARE RIVER.

The Delaware drainage area occupies parts of the States of New York, New Jersey, and Pennsylvania, comprising 6,855 square miles. (See fig. 12.) The main river of the Delaware system rises in New York State, in a county bordering the western part of the Catskill Mountains. The elevation at that point is said to be about 1,900 feet. It flows in a very irregular course, its general direction being southward, and empties into Delaware Bay. For about 100 miles above Port Jervis it forms the boundary between the States of New York and Pennsylvania; below that point it forms the entire western boundary of the State of New Jersey.

The principal tributaries of Delaware River enter from the west. They consist of the Schuylkill, which joins the main stream at Philadelphia, draining a country 1,912 square miles in extent; and, a little farther north, the Lehigh, at Easton, the basin of which, 1,332 square miles in extent, comprises a great mining region of Pennsylvania. The Lackawaxen River enters at Lackawaxen, draining in its course 597 square miles. At the extreme northwestern part of the Delaware basin the river forks into the East and West branches, which drain 520 and 348 square miles, respectively.

Although the drainage basin of the Delaware is a very important, prosperous, and thickly-settled region, the resources of the river system have not been utilized or appreciated to any considerable extent, and comparatively little has been done to determine the character of the water. At Philadelphia the city is now conducting extensive investigations, which, when their results become available, will furnish a clear insight into the character of the water in the Schuylkill and Delaware opposite that city. Aside from these investigations, the results of which can not be learned at present, the only data available are comprised in a short report, by Mr. Allen Hazen, on the character of the water supply of the city of Trenton, N. J., which demonstrated beyond controversy that the water of the Delaware above the city of Trenton is polluted with sewage and industrial refuse to a dangerous degree.

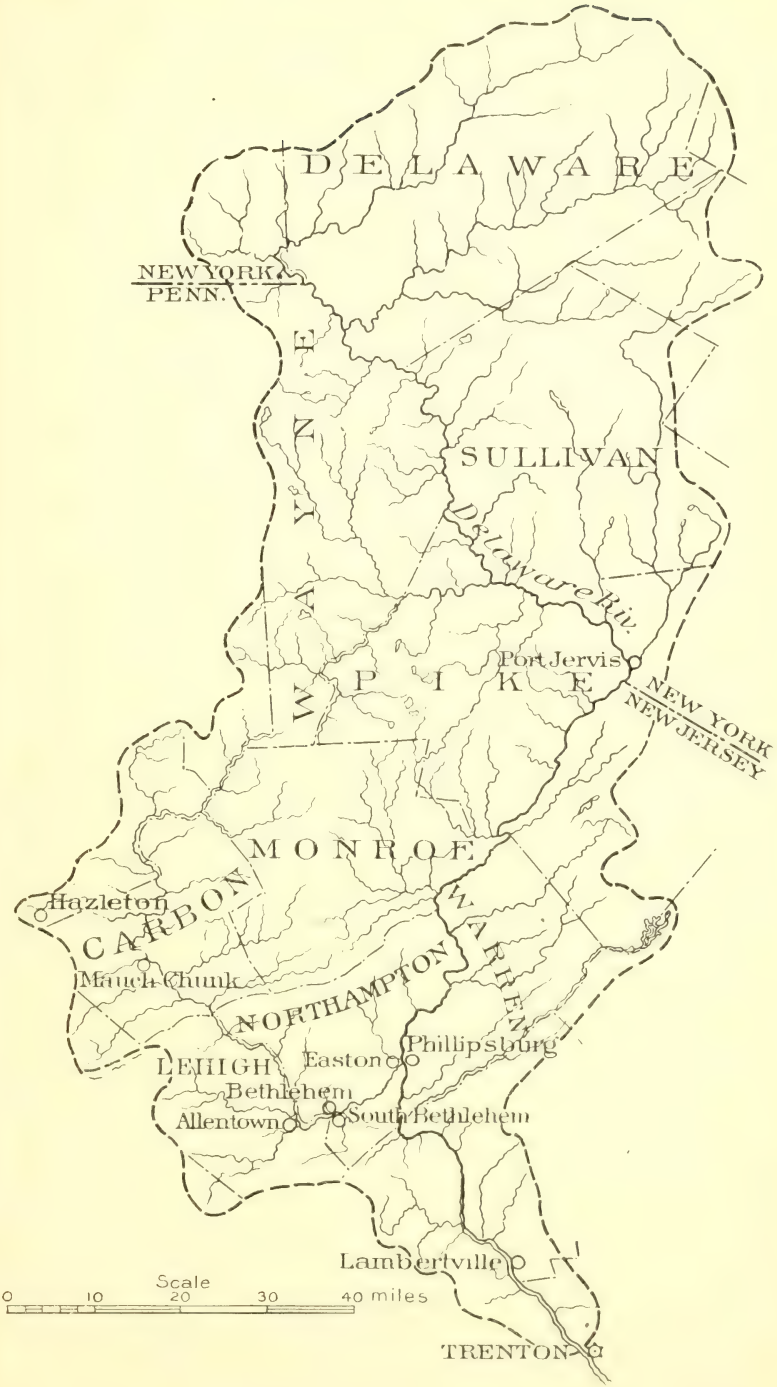

FIG. 12.—Delaware River drainage basin.

The following table, taken largely from Mr. Hazen's report, gives the names of the municipalities in the Delaware Basin above Trenton contributing polluting substances to the river:

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River.*

[Drainage area, 6,916 square miles.]

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Lambertville, N. J	Hunterdon	14	4,637
Newhope, Pa	Bucks	14	1,218
Frenchtown, N. J	Hunterdon	30	1,020
Quakertown, Pa	Bucks	42	3,014
Phillipsburg, N. J	Warren	47	10,052
South Easton, Pa	Northampton	48	25,238
Easton, Pa	do	48	
Bangor, Pa	do	56	4,106
Nazareth, Pa	do	58	2,304
Bethlehem, Pa	do	59	7,293
South Bethlehem, Pa	do	59	13,241
West Bethlehem, Pa	Lehigh	60	3,465
Washington, N. J	Warren	60	3,580
Belvidere, N. J	do	62	1,784
Allentown, Pa	Lehigh	64	35,416
Penn Argyl, Pa	Northampton	65	2,784
Catasauqua, Pa	Lehigh	67	3,963
Oxford, N. J	Warren	71	3,095
East Stroudsburg, Pa	Monroe	71	2,648
Slatington, Pa	Lehigh	79	3,773
Stroudsburg, Pa	Monroe	81	3,450
Lehighton, Pa	Carbon	90	4,629
East Mauchchunk, Pa	do	93	3,458
Mauchchunk, Pa	do	93	4,029
Summithill, Pa	do	95	2,986
Nesquehoning, Pa	do	98	2,862
Waverly, Pa	do	100	2,471
Newton, N. J	Sussex	105	4,376
Whitehaven, Pa	Luzerne	115	1,517
Hazleton, Pa	do	115	14,230
Port Jervis, N. Y	Orange	120	9,385
Hawley, Pa	Wayne	157	1,925
Honesdale, Pa	do	166	2,864

TABLE 78.—*Cities and towns above Trenton contributing polluting substances to Delaware River*—Continued.

City or town.	County.	Distance above Trenton.	Population, 1900.
		Miles.	
Hancock, N. Y	Delaware	194	1,883
Deposit, N. Y	do	205	2,051
Walton, N. Y	do	228	2,811
Delhi, N. Y	do	245	2,078

Although only a few of the municipalities mentioned in the above table have been provided with sewers, and the pollution is therefore in an early stage of its development, the effects are noticeable in the following analyses, which were made during the period of Mr. Hazen's investigation:

TABLE 79.—*Analyses of water from Delaware River at Trenton.*

[Parts per million.]

Date.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Apr. 16	3	0.15	0.060	0.004	0.000	0.260	1.7	44.50	23.0	6.0	0.30
June 29	680	.18	.350	.040	.004	.160	1.6	480.00	27.0	8.0	11.80
July 6	7	.12	.088	.042	.003	.320	2.2	93.00	42.0	9.5	.05
July 27	480	.12	.226	.086	.004	.160	2.0	273.00	27.0	9.5	8.00
Aug. 17	3	.11	.102	.018	.006	.160	2.8	116.00	57.0	7.5	.20
Sept. 13	8	.08	.116	.024	.004	.160	3.0	103.00	57.5	14.0	.30

The investigation included a daily determination of turbidity from April to November, inclusive, in the year 1889, the results of which show that the Delaware water is usually free from suspended matter, and that, although it carries along considerable mud during freshets, subsidence is rapid.

TABLE 80.—*Turbidity of Delaware River at Trenton.*

Day of month.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1		6	6	9	13	6	6	6
2		6	6	9	13	6	6	6
3		6	9	6	9	6	6	6
4		6	9	6	13	6	6	6
5		6	9	6	6	6	6	6
6		6	9	6	6	6	6	6
7		6	9	6	6	6	6	6
8		6	6	28	6	6	6	6
9	6	6	6	13	6	6	44	13
10	6	6	6	9	6	6	6	9
11	6	6	6	6	6	6	6	6
12	6	6	6	6	6	6	6	6
13	6	6	6	6	6	6	6	6
14	6	6	6	6	16	6	400	6
15	6	6	77	6	6	6	100	6
16	6	6	77	6	6	150	56	6
17	6	6	32	6	6	32	13	6
18	6	6	32	6	6	20	6	6
19	32	2,737	28	6	6	13	6	6
20	28	28	16	6	6	9	6	6
21	16	28	9	6	6	9	6	6
22	16	28	6	6	6	6	6	6
23	16	24	6	6	6	6	6	6
24	16	24	6	6	6	6	6	6
25	13	9	6	6	6	6	6	6
26	13	9	6	28	6	6	6	
27	13	9	6	77	6	6	6	
28	9	9	236	56	6	6	6	
29	9	9	16	40	6	6	6	
30	6	6	16	32	6	6	6	
31		6		150	6		6	

OHIO RIVER BASIN.

DRAINAGE AREA.

A clear and concise description of the drainage area of the Ohio River is given in the report of Prof. Dwight Porter, published in Volume XVII of the Report of the Tenth Census, as follows:

By the union of the Allegheny and Monongahela rivers at Pittsburg the Ohio River is formed, with a drainage basin at that point of between 18,000 and 19,000 square miles, which, after a course of nearly a thousand miles to the southwest,

is increased to about 214,000 square miles at the junction with the Mississippi. The principal streams which contribute to this increase are, on the north side, the Beaver, Muskingum, Scioto, Great Miami, and Wabash rivers, and on the south side the Little Kanawha, Great Kanawha, Big Sandy, Licking, Kentucky, Green, Cumberland, and Tennessee. The headwaters of the Allegheny are in northern Pennsylvania and southwestern New York; those of the Monongahela, nearly 250 miles distant, in West Virginia. The eastern watershed line of the Ohio therefore cuts directly across the State of Pennsylvania, at a distance from the western border ranging from 80 miles in the south to about 130 miles in the north. Passing out of this State, the northern boundary of the river basin runs through New York, Ohio, and Indiana, being carried in the latter State around the upper waters of the Wabash nearly to the Michigan line and considerably more than 200 miles north of the main river itself; it then enters Illinois and strikes southerly through that State to the mouth of the Ohio at Cairo. The southern boundary runs from Pennsylvania across a corner of Maryland, embraces nearly all of West Virginia, and forms in part the dividing line between that State and Virginia; it crosses the southwestern portion of the latter State and the western part of North Carolina, and by the Tennessee Basin is extended down into Georgia and Alabama, reaching there a distance of 300 miles south of the Ohio; it continues from Alabama across the adjacent northeastern corner of Mississippi, and finally traverses the extreme western portions of Tennessee and Kentucky.

The characters of the different streams within this area are determined or modified by the various topographic features of the country. In the east and southeast the drainage area is bordered by the Allegheny Mountains, and the streams which have their origin there flow into the Ohio through a generally sparsely settled country rich in mineral deposits. From this region across to Mississippi River the surface grows flatter, rapidly in some directions, more gradually in others. Toward the Ohio there is a gradual decline in elevation, culminating in the bottom lands along that river, which have become famous for their fertility. North of Ohio River the land comprising that portion of the basin lying within the States of Ohio and Indiana rises very slowly, through many miles of undulating territory, and ends in a low range of hills which forms the divide between the Ohio Basin and the drainage area of the Great Lakes.

The various tributaries on the south side of the Ohio offer facilities for extensive development of power. The descent of the streams is swift, especially in the southern portion, but the flow is extremely variable, the drainage areas being of the "quick-spilling" variety, and consequently enormous pondage would be necessary to secure any great measure of uniformity of flow. In the case of some streams this would make the initial cost of utilization extraordinary and prohibitive. On the north side of the Ohio the country is flat and the proportion of run-off is small, so that, as a whole, the streams are not well adapted for the development of power. It is true that there has been considerable utilization of streams for local grist and lumber mills, yet it is not at all proportional to the contributing drainage area as compared with that which is possible on the streams of New

York and New England. The Ohio is therefore in only a comparatively limited sense a power stream.

The main river has great value as a channel of transportation, and some of the tributaries are navigable to a limited extent. This value has been developed largely by the Federal Government.

CHARACTER OF WATER.

In considering the characteristics of the waters of the Ohio Basin one can not fail to be impressed with the marked differences which exist between them and the waters of the Northeastern States, already considered at length. In the latter region we have studied waters which are, as a rule, fairly clear, which contain only small amounts of dissolved mineral matter, and in which the degree of hardness is usually almost insignificant. We have noted that the New England waters are highly colored, some extremely so, from the solution of chlorophyll and decaying vegetable and peaty matter. This characteristic has led to the application to these waters of the apt and expressive term "vegetable tea." In considering the water in the Ohio Basin it is necessary to remember in the beginning that we have to deal with a water which usually contains a high proportion of inorganic salts, which is hard, and which in times of freshet carries along enormous quantities of fine clay and mud. A report of a water analysis which, in the case of a New England water, would be regarded as certain evidence of artificial pollution, may in the case of Ohio water represent a truly normal river of uncontaminated and healthful character.

The following analyses illustrate this point:

TABLE 81.—*Comparison of analyses of normal waters in New England and in the Ohio Basin.*

[Parts per million.]

	Region.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			
1	Massachusetts	Very slight.	6.6	0.199	0.013	0.000	0.037	1.7	34.7	8.0
2	Ohio Basin	do	4.0	.514	.062	.024	1.500	2.0	730.0	43.6

Sample No. 1 in the above series was a normal water taken from an upland stream in Massachusetts. It is a fair representative of Eastern waters, having some turbidity, a high color, and considerable organic matter, as is shown by the nitrogen compounds. Sample No. 2 was a normal water taken from an upland region in the Ohio Basin

above all points of contamination. It also is a good representative of waters of its class, having a moderate color, a large residue, and an extremely high content of nitrogen, especially in the form of nitrates. Note also that the water is very hard. From the standpoint of sewage pollution both of the above samples are equally good, each being uncontaminated. From the sanitary standpoint No. 2 is the equal of No. 1, and if these analyses faithfully represented the character of the streams from which these samples come the resources of one would be equal to those of the other, other things, of course, being equal.

Another point to be borne in mind is the extreme variability of the physical characteristics of the Ohio Basin waters, especially the turbidity. In a time of drought the water will be clear, but soon after a rainstorm the turbidity will rise to a point which almost defies clarification, but in the course of a few days the water will become as clear as it was before the storm.

ALLEGHENY RIVER.

GENERAL FEATURES.

Drainage area.—The Allegheny is the largest contributor to the Ohio. (See fig. 13.) The drainage area covers 11,400 square miles and lies principally in the State of Pennsylvania, extending for a short distance into the State of New York. The length of the stream is about 325 miles, and its basin embraces a large area of the western slope of the Allegheny Mountains. The country is rough and broken, with high summits and deep valleys.

Water power.—The Allegheny is not very valuable as a source of water power. The storage capacity in the drainage area is extremely small; and although in early times the large number of springs maintained a fairly constant flow, the deforestation has reduced the whole area to a "quick-spilling" country. Although the drainage area is large, only a small portion of it contains streams that are valuable for development of power. The river is peculiar in this respect, for the descent is more rapid in the middle and lower portions than it is at the headwaters. In those portions it is deep and is used extensively for transportation, but above the head of navigation it has little value. The power which has been developed is applied mainly to the lumber industry.

Flow.—The flow of the Allegheny has not been definitely determined, and the figures available to show it are not the result of as careful and long-continued measurement as is generally considered necessary for the accurate determination of flow.[a] Measurements made in 1897 under the direction of a corps connected with the War Department seem to show that the flow of the Allegheny at Franklin

[a] See Twentieth Annual Rept. U. S. Geol. Survey, Part IV, p. 195.

was about 1,000 second-feet, and at another point 20 miles below a discharge of 1,250 second-feet was determined. In the year 1838 the discharge of the Allegheny at Pittsburg was reported as being 1,330 second-feet, while various gagings during the years 1866–1870 showed

FIG. 13.—Allegheny River drainage basin.

that at Brunots Island, 2½ miles below the junction of the Allegheny and the Monongahela rivers, the least discharge was 1,700 second-feet.

POPULATION OF BASIN.

In the drainage basin of Allegheny River the population has increased rapidly. The following table includes the most important

cities and towns, their population in 1890 and 1900, and their approximate distance from the city of Pittsburg:

TABLE 82.—*Cities and towns on Allegheny River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.		Place.	Distance in miles.	Population.	
		1890.	1900.			1890.	1900.
Verona	3	1,477	1,904	Titusville	142	8,073	8,224
Oakmont	4	1,678	2,323	Meadville	144	9,520	10,291
New Kensington	11	.....	4,665	St. Marys	148	1,745	4,295
Tarentum	14	4,627	5,472	Johnsonburg	149	1,280	3,894
Freeport	21	1,637	1,754	Wilcox	151	.....	.....
Ford City	33	1,255	2,870	Tidioute	160	1,328	1,237
Apollo	35	2,156	2,924	Edinboro	161	1,107	691
Kittanning	38	3,095	3,902	Waterford	170	838	767
Saltsburg	47	1,088	828	Sheffield	172	2,202	2,580
Red Bank	57	2,035	1,961	Union	177	2,261	3,104
East Brady	62	1,228	1,233	Clarendon	180	1,279	1,092
Latrobe	64	3,589	4,614	Warren	181	4,332	8,043
Blairsville	65	3,126	3,386	Corry	195	5,677	5,369
Derry	72	1,968	2,347	Busti, N. Y	205	.....	.....
Parker	76	1,317	1,070	Jamestown, N. Y	210	16,038	22,892
New Bethlehem	77	1,026	1,269	Randolph, N. Y	212	1,201	1,209
Indiana	78	1,963	4,142	Salamanca, N. Y	222	3,692	4,251
Emlenton	82	1,126	1,190	Mayville, N. Y	227	1,164	943
Punxsutawney	85	2,792	4,375	Bradford	240	10,514	15,029
East Conemaugh	92	1,185	2,175	Olean, N. Y	241	7,358	9,462
Brookville	98	2,478	2,472	Cuba, N. Y	256	1,386	1,502
South Fork	99	1,295	2,635	Franklinville, N. Y	258	1,021	1,360
Clarion	100	2,164	2,004	Eldred	263	1,050	963
Ebensburg	112	1,202	1,574	Port Allegany	266	1,230	1,853
Reynoldsville	112	2,789	3,435	Smethport	267	1,150	1,704
Franklin	116	6,221	7,317	Coudersport	282	1,530	3,217
Du Bois	121	6,149	9,375				
Oil City	125	10,932	13,264				
Ridgway	140	1,903	3,515				

POLLUTION.

Inspection of the above table will show that although a great majority of the municipalities are small, and probably do not contribute a large amount of sewage or manufacturing wastes to the river, there are, nevertheless, many places that are probably sewered and that naturally pour their wastes into the river. There is no

record of any examination of the water of the Allegheny River except those made by the filtration commission of the city of Pittsburg.

The question of pollution has been considered in a report made by Prof. William T. Sedgwick to the Pittsburg commission, the conclusions of which were that the water is polluted to a degree which makes it unfit for use as a source of public supply in its raw state. This opinion is borne out by recent use of the water in Pittsburg. The records show that the typhoid fever rate is abnormal. Accordingly, the city of Pittsburg has investigated, and is even now preparing to introduce a system of filters, the total cost of which will not be far from $3,500,000, while the expense of maintenance is calculated in the report of Mr. Allen Hazen, consulting engineer, to be about $200,000 annually. This gives no idea of the damage done to the city of Pittsburg alone by sewage pollution. In a well-considered article published in the Pittsburg Dispatch April 21, 1902, it was estimated that the cost of treating typhoid fever and the value of the lives lost from that disease in the city of Pittsburg during the previous three years amounted to about $3,335,000, sufficient to pay interest upon and retire a bonded indebtedness of $13,000,000. These figures were charged to the account of typhoid fever alone, no estimate being made of the sickness and deaths arising from or induced by other water-borne diseases.

CHARACTER OF WATER.

Experiments were conducted during the years 1897–98, under the authority of the filtration commission, and throughout this period weekly chemical examinations were made of the water in the Allegheny River. These results are almost the only available ones which show the character of the water; and as the samples were taken a short distance above the city of Pittsburg, they show clearly what is being contributed to the Ohio system by this branch.

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, above Pittsburg.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
June	Decided	.....	0.137	0.006	0.000	0.175	24.0	141	.....	.....	.....
July	do	.....	.347	.034	.001	.106	31.3	269	60.8	.....	1.84
August	Slight	.....	.210	.023	.000	1.050	20.3	90	40.5	13.9	.07
September	do	3.7	.133	.019	.000	.650	27.0	131	46.3	4.0	.63
October	do	2.3	.120	.017	.000	.550	38.1	177	50.9	4.0	.40
November	do	2.9	.152	.019	.000	.700	31.5	197	35.1	3.8	.95
December	do	3.0	.111	.015	.000	1.075	21.1	237	17.2	5.2	1.23

TABLE 83.—*Analyses of water of Allegheny River at Brilliant, etc.*—Continued.

Date of collection.	Turbidity.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Iron.
1898.											
January	Slight	2.8	.074	.016	.000	.885	15.3	153	14.8	6.1	1.12
February	do	2.1	.099	.020	.000	1.425	14.6	119	17.3	8.6	.59
March	Muddy	2.4	.076	.015	.000	.487	12.9	140	17.5	9.7	.40
April	Slight	2.2	.077	.018	.000	.458	13.6	94	18.3	4.6	.41
May	Decided	3.0	.164	.015	.000	1.80	16.6	207	21.3	6.7	.33
June	76	2.5	.085	.019	.000	.375	24.2	191	31.0	4.0	.10
July	361	2.7	.100	.027	.000	.694	24.7	131	34.1	11.7	.20
August	105	3.1	.130	.214	.000	.435	24.2	195	31.5	8.4	.20

A mineral analysis made of the samples from the river collected September, 1898, gave the following results:

TABLE 84.—*Mineral analysis of water from Allegheny River.*

[Parts per million.]

Total solids	127.0
Loss on ignition	43.0
Calcium oxide	20.4
Magnesium oxide	4.9
Sulphuric acid	16.1
Chlorine	22.0
Silica	1.0
Iron oxide	.1

The analyses set forth in Table 83 certainly do not necessarily indicate a water of dangerous qualities. Albuminoid and free ammonia and nitrites are low, and on the whole the analyses present an extremely favorable appearance. This, then, is one of the cases in which, as stated in the introduction to this work, little can be determined concerning the dangerous qualities of a river from chemical examinations alone. Inspection of the map shows that the centers of contamination above Pittsburg on the Allegheny River are far removed from that city, and the distances intervening seem sufficient to bring about all the purification apparent in the result of the analyses above set forth; yet, as pointed out by Professor Sedgwick in the report already referred to, the velocity of the Allegheny is high, being at times from 7 to 8 miles an hour. Under such circumstances pollution poured into the river at Oil City, for instance, would reach Pittsburg with fifteen hours, and at a slower rate of flow would certainly arrive within a few days, at least. Now, it can be easily understood that although organic matter may be oxidized and diluted to such an extent that it would appear in an analysis in small proportion only, germs of disease entering the river with such pollution could arrive

at the Pittsburg water "intake" in a virulent condition. Undoubtedly such has been the case during all the years in which Pittsburg has suffered abnormal typhoid-fever morbidity.

Coincident with the examinations above described, other points along the Allegheny were made use of for the collection of samples. A series was collected at Montrose, the intake for the water supply of the city of Allegheny, 4 miles above Brilliant, at Pittsburg. Another series was taken at Hulton, where the intake for the supply of Oakmont and Verona is situated, 6 miles above Brilliant, and a third at Wildwood, 1⅓ miles above Brilliant, whence the water is taken to supply Wilkinsburg and the First Ward of the city of Pittsburg. These examinations, however, did not show that the water was materially different from that at Brilliant, and, indeed, when the rapid flow of the river is taken into account, this might have been expected. There were, however, a number of examinations of samples of water taken at Etna, 2 miles below Brilliant, on the opposite side of the Allegheny, below a point where a certain amount of pollution is received from Pittsburg, and another series of examinations of samples taken at Millvale, 4 miles below Brilliant, also on the opposite side of the river. The average of these examinations for each point is given in Table 85. It will be seen that these do not differ materially from the samples taken at Brilliant, even though the water is undoubtedly contaminated by the addition of Pittsburg and Allegheny sewage. The reasons for this will be discussed presently.

TABLE 85.—*Analyses of water from Allegheny River at Etna and Millvale.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.	Number of samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal.		
Etna	2.9	0.119	0.030	0.000	0.682	18.6	155	32.7	5.6	0.70	35
Millvale	3.1	.149	.045	0.000	.706	25.8	147	47.0	8.5	.38	16

MONONGAHELA RIVER.

Drainage basin.—Monongahela River, which joins the Allegheny at Pittsburg to form the Ohio, has a drainage area of 7,625 miles. (See fig. 14.) It rises in the northern part of West Virginia and flows in a northerly direction, draining a part of the western slope of the Allegheny Mountains, most of which has a rugged character and lacks fertility. The region, once heavily timbered, has been very thoroughly cleared, except at the headwaters of the streams. The lower reaches of the river are fertile and yield a large crop of corn, but the country seems to be especially adapted to grazing.

Flow.—The flow of the Monongahela has not been determined in a manner more satisfactory than that of the Allegheny. In the year 1838 the flow of the Monongahela at Brownsville, 50 miles above Pittsburg, was reported to be only about 230 second-feet. This, however, was in a dry season. The lower reaches of the river constitute a "slackwater" basin, with a flow of not more than 1 foot per minute.

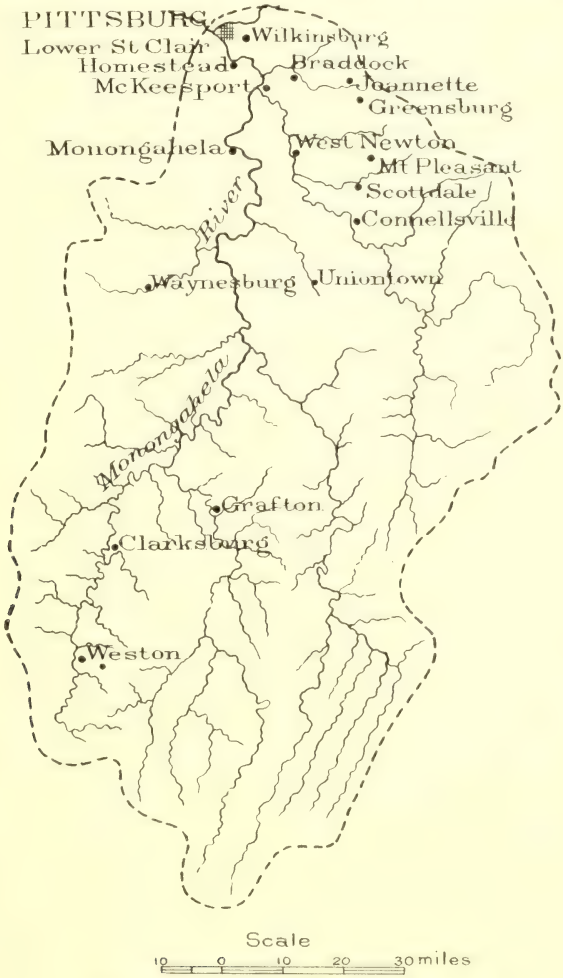

FIG. 11.—Monongahela River drainage basin.

Population of basin.—The population in the Monongahela Basin is denser than in the Allegheny, and there are larger cities, such as McKeesport; Homestead, Braddock, and Wilkinsburg, which are situated well down toward the mouth of the river. Therefore, the water which arrives at Pittsburg contains more recent pollution than that in the Allegheny. The important difference, however, lies in the fact that the flow of the Monongahela, as has been said, is slow, and there is the opportunity for sedimentation that arises in quiescent water.

TABLE 86.—*Cities and towns on Monongahela River and tributaries above Pittsburg.*

Place.	Distance in miles.	Population.	
		1890.	1900.
Lower St. Clair	3	3,680	4,638
Homestead	6	7,911	12,554
Braddock	9	8,561	15,654
Wilkinsburg	9	4,662	11,886
Port Perry	11	1,031	1,267
Turtle Creek	12	----	3,262
Wilmerding	13	419	4,179
McKeesport	14	20,741	34,227
Elizabeth	20	1,804	1,866
Irwin	23	2,428	2,452
Jeannette	29	3,295	5,865
Monongahela	29	4,096	5,173
West Newton	32	2,285	2,467
Greensburg	33	4,202	6,508
Belle Vernon	41	1,147	1,901
Everson	50	----	----
Scottdale	52	2,693	4,261
Brownsville	52	1,471	1,552
Bridgeport	55	1,030	1,805
Mount Pleasant	57	3,652	4,745
New Haven	57	1,221	1,532
Connellsville	57	5,629	7,160
Dunbar	61	1,381	1,662
Uniontown	69	6,359	7,344
Waynesburg	80	2,101	2,544
Fairchance	95	1,092	1,219
Morgantown, W. Va	95	1,011	1,895
Somerset	112	1,713	1,834
Meyersdale	112	1,847	3,024
Fairmont, W. Va	120	1,023	5,655
Grafton, W. Va	140	3,159	5,650
Clarksburg, W. Va	150	3,008	4,050
Weston, W. Va	180	2,143	2,560
Buckhannon, W. Va	180	1,403	1,589

Character of water.—The increase of population, amounting to 75 per cent, as shown by the table presented above, is sure to bring about a proportional increase in pollution. It is not necessary to examine the water chemically or bacteriologically to prove that it is

unfit for use as a water supply. McKeesport, with a population of 34,227; Braddock, with 15,654; Homestead and Wilkinsburg, each following closely in the number of inhabitants, empty raw sewage into the Monongahela or its branches, and this must necessarily produce a condition which is a detriment not only to the water itself, but to the realty values along the river.

There are available a few analyses of the water of the Monongahela and some of the branches, which were made at Pittsburg at the same time as those already presented upon the Allegheny. A series of chemical examinations made of the water of Indian Creek and other creeks in its vicinity give a good idea of the character of the normal water of that section of the country, for the population on Indian Creek drainage area is small, is not at any point provided with sewerage, and is sufficiently well scattered to keep the water in its normal state, or nearly so.

TABLE 87.—*Analyses of water from Indian Creek and vicinity.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.			Average of how many samples.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	Iron.	
Indian Creek	1.5	0.101	0.028	0.000	0.480	4.9	112	20.0	0.4	0.34	12
Mill Run	2.1	.128	.027	.000	.532	4.5	258	20.3	.5	.09	14
Laurel Hill Creek	1.7	.065	.039	.000	.675	3.9	35	20.7	.5	.01	3
Castleman River	1.7	.069	.055	.000	.750	4.6	84	15.3	5.3	.01	3
Youghiogheny River	1.5	.128	.062	.000	.975	3.5	40	17.6	.4	.01	2

Coming down to Pittsburg again, we find a series of analyses made of the water just above the city.

TABLE 88.—*Analyses of water from Monongahela River at Pittsburg.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.										
June		0.136	0.081	0.000	0.740	13.5	154			
July		.186	.076	.001	.768	4.3	141	28.5	21.2	1.95
August	1.0	.173	.100	.001	1.121	10.7	129	19.5	37.8	1.93
September	2.6	.130	.119	.000	.979	9.5	145	16.4	41.5	.30
October	1.2	.403	.142	.000	1.261	15.5	285	9.0	55.2	.15
November	1.9	.194	.145	.000	.825	14.7	265	14.1	48.4	1.33
December	2.5	.166	.030	.000	1.275	13.1	328	14.3	17.2	2.72

TABLE 88.—*Analyses of water from Monongahela River, etc.*—Continued.

Date of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Iron.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
January	2.1	.095	.030	.000	1.245	9.1	298	13.8	15.2	2.06
February	2.0	.177	.021	.000	1.500	11.1	219	13.2	22.4	1.29
March	2.0	.080	.025	.000	.425	9.2	203	10.4	39.9	.28
April	2.1	.097	.018	.000	.450	8.2	127	11.5	12.0	.19
May	2.8	.125	.026	.000	.275	12.1	167	14.6	25.9	.13
June	2.1	.105	.096	.000	.375	14.2	155	11.2	21.5	.04
July	2.2	.126	.041	.000	.825	14.2	170	12.8	33.6	.06
August	3.0	.190	.050	.000	.375	5.2	292	16.2	3.2	.06

Although, as has been stated, the sewage pollution of the Monongahela is more extensive near that city than in the Allegheny, it will be seen by comparison of Tables 83 and 88 that the Monongahela contains a smaller amount of organic matter than the Allegheny. The reason for this well illustrates what has already been said concerning the water of the Ohio Basin. The normal content of organic matter is so high that under ordinary circumstances the organic matter which is added to the river by the disposal of sewage therein does not increase the total amount to a significant degree. In other words, the amount of organic matter in the Ohio Basin is insignificant from the standpoint of sewage pollution, because of the fact that the unpolluted water often carries a larger amount of organic matter than the sewage brought into it. The two rivers under discussion well illustrate this point. We have in the Allegheny a "quick-spilling" basin, out of which is carried at times enormous amounts of sediment, consisting in a large measure of organic matter. The river flows swiftly, and there is little or no opportunity for sedimentation, so that when the water reaches Pittsburg its condition is not greatly improved nor changed.

In the Monongahela, on the other hand, we have a slack-water basin. Large amounts of silt are poured into it from the tributaries, as large as or larger than the amounts brought into the Allegheny. Yet because of the fact that there is ample opportunity in the slack water of the main river for subsidence, the water appears better upon chemical examination at Pittsburg in spite of the fact that comparatively large amounts of sewage are poured into the Monongahela only a short distance above. These facts illustrate excellently the point just enunciated; namely, that under ordinary circumstances the amount of organic matter emptied from sewers into the Ohio Basin

is small in comparison with that which is brought into the river from natural sources.

This consideration brings up the question of the value of determinations of organic matter in water, and seems to indicate that such determinations are of little aid in an investigation of this nature, if they are not indeed entirely useless. At all events, one should be very careful in regard to his premises before attempting to draw conclusions from determinations of organic matter.

MAHONING RIVER.

NATURAL RESOURCES.

Drainage area.—The area of the Ohio Basin next below the confluence of the Allegheny and the Monongahela rivers in which investigations have been made, the results of which have been published, is that of Mahoning River. This river drains 1,300 square miles in the eastern part of Ohio, being bounded on the north by the Lake Erie divide and on the south by the Muskingum and several other small streams, which enter the Ohio direct (see fig. 15).

The Mahoning rises in Columbiana County, Ohio, flows through the northeast corner of Stark County, and then by a circuitous course enters Portage, Trumbull, and Mahoning counties, flowing first in a northeasterly and then in a southeasterly direction, crossing the Ohio line and emptying into Beaver River in Pennsylvania, 8 miles from the Ohio boundary. Beaver River in turn enters the Ohio 40 miles below Pittsburg.

The basin of the Mahoning is rolling in some portions, while in others it is decidedly flat. It is rich in minerals and is extremely fertile. The valley is an important manufacturing place and is well supplied with transportation facilities. Under such favorable circumstances the population is rapidly increasing and the country is uncommonly prosperous.

Power.—The Mahoning is one of the best power streams in the Ohio Basin, and has been developed to an unusual extent as compared with other streams in this part of the country. Prof. Dwight Porter states that in the year 1880[a] 36 mills were situated upon the river, utilizing a total fall of 442½ feet, developing a horsepower of 1,146. It is probable that numerous changes have been made since that time in conformity with the decline of Ohio power values, and the figures are not applicable at the present date. The power developed is applied almost entirely to the grist and lumber business.

Flow.—There appear to be no satisfactory gagings of the flow of the river. In the report of the Ohio State Board of Health for 1898 there are given the results of a few measurements covering a period

[a] Tenth Census, vol. 17, pt. 2, p. 465.

of five months during a very dry season, but, as explained in that report, the gagings were attended by unfortunate circumstances which almost entirely vitiate their value, and they were not in any event continued for a sufficient period to indicate the normal flow of

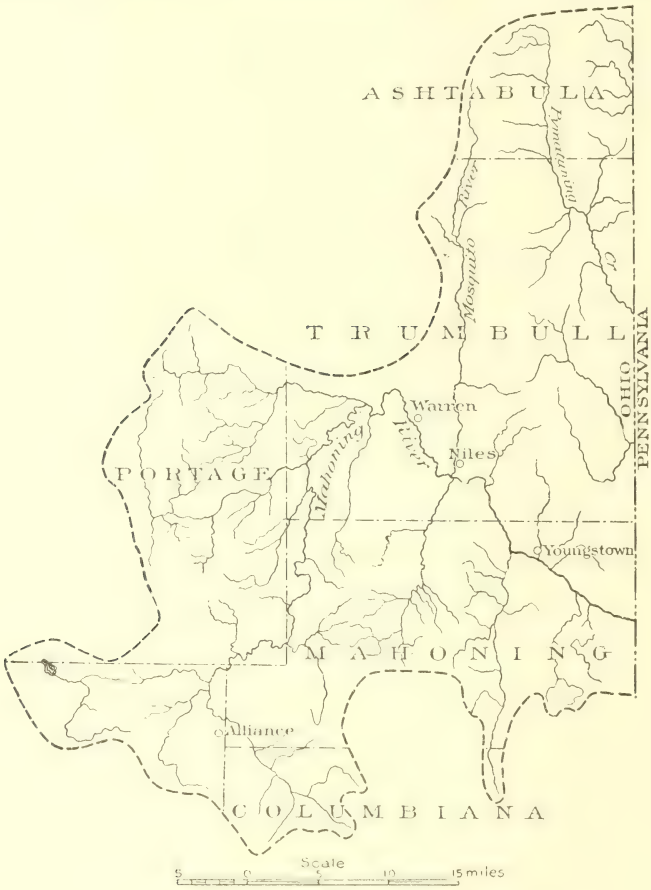

FIG. 15.—Mahoning River drainage basin.

the stream. The common observation is that the river fluctuates widely and is subject to freshets.

CHARACTER OF WATER.

No records of examinations of unpolluted water in the Mahoning Basin have been found. The excellent work of the State Board of Health was confined to districts undoubtedly polluted and therefore gives no idea of the character of the normal water in this basin. It is probable that the unpolluted surface water in the Mahoning Basin does not differ widely in character from that indicated by the analyses of the water of the river above Alliance, which will be shown below.

Alliance is a city of 8,974 inhabitants (census of 1900), and is situ-

ated in the upper part of the Mahoning Basin. Therefore it is the head of the extensive pollution for that basin. Above Alliance the drainage area comprises 73 square miles, and the population is not far from 60 per square mile. There are no mills nor factories on the river, and the country is largely devoted to manufacturing and dairying. There are six small villages on the river, the largest having probably no more than 300 inhabitants. Under some circumstances dangerous pollution might arise at two, North Georgetown and Damascus. Two miles above Alliance is situated the Fairmont Children's Home, which shelters about 200 persons, and pours raw sewage into the river. Under such circumstances when the water reaches the intake of the Alliance Waterworks it is generally in an acceptable condition, but is subject to the dangers above noted. The intake is well down toward the center of the city, so that there is undoubtedly a certain amount of contamination from Alliance itself.

TABLE 89.—*Analyses of water from Mahoning River above Alliance.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 19	None	4.5	0.528	0.136	0.012	0.23	1.5	240	110	36
July 24	Slight	7.0	.478	.126	.010	.28	.2	175	70	38
Sept. 2	Distinct	4.0	.399	.094	.005	.07	2.3	400	136	54
Sept. 29	None	1.5	.136	.059	.003	.00	3.0	415	182	58
Oct. 27	Very slight	2.0	.150	.060	.000	.00	3.2	410	204	54
Nov. 26	Decided	10.0	.592	.114	.007	6.5	2.3	470	78	64
Average			.379	.100	.006	.21	2.1	350	130	51

During the periods covered by the above table the rainfall at Akron, the nearest weather observation station, was as follows:

TABLE 90. *Rainfall at Akron, Ohio.*

	June.	July.	August.	September.	October.	November.	Whole period.
Total fall	1.55	5.06	2.90	1.07	1.65	4.85	17.16
Variation	2.81	1.20	.35	2.12	.77	+1.69	3.16

The city of Alliance is provided with a system of water supply, and the consumption approaches 5,000,000,000 gallons daily. The sewer-

age system introduced in 1896 has been well extended, and in the year 1898 poured into the chemical precipitation works 300,000 gallons of sewage daily. The purification works do not seem to be extremely efficient, if we may judge from the analyses and bacteriological examinations made by the Ohio State Board of Health. The report of the bacteriologist in the year 1898 makes the following statement with reference to the Alliance sewage disposal:

At this town there is in operation sewage-disposal works which take care of the sewage by chemical precipitation. Examinations made at the works themselves showed that so far from this method destroying bacteria or lessening the number, the effluent from the works which discharged into the river was many times richer in bacteria than the original sewage, though the curve in general runs parallel with the curve above the station.

TABLE 91.—*Analyses of water from Mahoning River below Alliance.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 19	None	3.0	0.422	0.200	0.022	0.07	3.0	310	128	56
July 24	Slight	8.0	.520	.196	.020	.33	.2	165	56	34
Sept. 2	do	3.0	.422	.122	.015	.12	4.8	410	138	68
Sept. 29	None	2.0	.366	.473	.035		9.0	415	170	68
Oct. 27	do	4.0	.356	2.100	.055	.03	15.5	480	216	98
Nov. 26	Decided	5.0	.390	.176	.022	.54	4.5	380	102	98
Average			.412	.544	.028	.18	6.2	358	135	70

The next important center of population below Alliance is Warren, in Trumbull County, which in 1900 had 8,529 inhabitants. The area of the watershed above Warren is not far from 600 miles, and the density of the rural population is about 45 per square mile. Between Alliance and Warren there are a large number of small country villages, having a population of 3,500 or 4,000, the most important being Newton Falls and Leavittsburg. At both of these places dangerous pollution may be expected, as well as from the Trumbull County Infirmary, which contributes a certain amount of sewage above the intake of the Warren waterworks. The river receives contamination from these three points, from Alliance, and from the storm sewers at Warren, which enter the river just above the waterworks.

TABLE 92.—*Analyses of water from Mahoning River above Warren.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	0.3	0.370	0.062	0.002	0.09	2.0	190	92	16
July 23	Decided	12.0	.606	.156	.010	.23	.3	130	36	22
Aug. 28	Very slight	3.0	.336	.062	.000		3.5	245	100	28
Sept. 30	do	1.5	.180	.036	.005	.00	4.2	275	124	32
Oct. 28	Slight	3.0	.158	.018	.000	.00	3.7	235	140	14
Nov. 27	Decided	7.0	.440	.074	.009	.85	3.3	205	54	46
Average		3.0	.348	.068	.004	.20	2.8	213	91	26

In addition to this the industrial pullution is extensive. Within the city are situated numerous works, such as a rolling mill, tube works, and linseed-oil, flour, and paint mills, as well as a galvanizing plant, from which large quantities of waste acid are turned into the river.

TABLE 93.—*Analyses of water from the Mahoning River below Warren.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
July 24	Decided	10.0	0.552	0.204	0.010	0.28	2.1	170	40	36
Aug. 28	Very slight	3.5	.430	.096	.004	.06	4.5	235	90	26
Sept. 30	do	1.5	.194	.070	.005	.00	8.7	275	126	18
Oct. 28	Slight	3.0	.304	.102	.017	.13	42.5	325	136	30
Nov. 27	Distinct	8.0	.454	.098	.017	.86	5.0	270	56	56
Average		5.2	.387	.114	.011	.27	12.6	257	90	33

The next important place on Mahoning River below Warren is Niles, which has a population or 7,468. Between Warren and Niles there is little pollution of a dangerous character, and the water which reaches the latter place is not materially different from that shown in Table 93. At Niles, although there is no complete system of sewers, the pollution is extensive and dangerous. There are probably about

50 house connections, with short lines of pipe; but in addition to these there are works which contribute waste, notably a tin-plate and iron-galvanizing plant, which discharge chemicals, mostly of an acid nature, into the river. During the summer of 1897 the river was discolored for 9 miles below Niles and many fish were killed. In addition to this the outhouses connected with the industrial plants are situated upon the edge of the stream, as is also that of a large schoolhouse. The pollution is therefore constant and dangerous, especially in view of the fact that this place is only about 10 miles above the intake of the Youngstown waterworks.

Analyses were made of water taken from the river below Niles, and a comparison of the results with those of analyses of water taken below Warren shows increased pollution. As will be noted by comparisons of Tables 93 and 94, the increase in chlorine is enormous. This, however, is not due entirely to sewage pollution, but arises from the influx of water from several salt springs in the vicinity of Niles.

TABLE 94.—*Analyses of water from Mahoning River below Niles.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1898.										
June 18		3.5	0.392	0.126	0.007	0.05	4.0	200	102	24
July 23	Decided	12.0	.620	.144	.010	.25	.3	135	34	18
Aug. 28	Slight	3.0	.328	.130	.005	.01	4.5	255	100	26
Sept. 30	None	2.0	.208	.078	.004	.00	4.5	245	124	12
Oct. 28	Slight	3.0	.268	.244	.001	.06	6.2	250	140	3
Nov. 27	Decided	10.0	.516	.096	.009	.88	3.3	233	54	42
Average		5.5	.389	.136	.008	.21	3.8	220	92	91

The next important center of population below Niles is Youngstown, the largest city on Mahoning River, containing 44,885 inhabitants. The area of the Mahoning Basin above Youngstown is approximately 900 miles, about 50 per cent of the population of which is urban. Between Niles and the water-supply intake at Youngstown the principal points are Cortland, Mineral Ridge, Canfield, Mahoning City Infirmary, Girard, Columbiana, and a part of the city of Youngstown itself, containing approximately nearly 10,000 persons. These represent a total population of 16,352.

The pollution from these centers is not extensive, and only that from the upper end of Youngstown may be termed dangerous. The

quality of water as it arrives at the Youngstown intake is therefore superior to that which leaves Niles.

TABLE 95.—*Analyses of water from Mahoning River above Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	5.0	0.424	0.094	0.001	0.05	5.3	245	90	28
July 23	Decided	25.0	.716	.120	.005	.18	.3	145	22	20
Aug. 28	Very slight		.436	.112	.003	.07	4.0	200	56	24
Sept. 30	None	1.5	.192	.056	.004	Tr.	13.5	370	88	86
Oct. 28	do	3.0	.194	.052	.004	.04	15.2	380	106	60
Nov. 27	Distinct	20.0	.386	.096	.009	.46	5.0	255	64	54
Average		10.8	.391	.088	.004	.13	7.2	266	71	46

For some miles the Mahoning River flows through Youngstown. The city is provided with intercepting sewers, which carry all sewage below the water intake and discharge it into the river direct. After the addition of this sewage the water has the character shown in the following table.

TABLE 96.—*Analyses of water from Mahoning River below Youngstown.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.	
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.
1897.										
June 18	None	4.0	0.436	0.166	0.015	0.10	7.0	225	96	28
July 23	Decided	25.0	.908	.120	.010	.31	.5	220	26	38
Aug. 28	Very slight	8.5	.456	.218	.015	.27	6.5	215	64	28
Sept. 30	None	2.0	.268	.230	.030	.18	18.0	390	114	70
Oct. 28	do	5.0	.454	.750	.092	.27	25.2	405	130	78
Nov. 27	Distinct	20.0	.460	.150	.017	.56	5.7	283	52	58
Average		10.5	.497	.272	.030	.28	10.5	286	80	50

There are no analyses or public records applying to points below those indicated in Table 96; therefore the character of the contribution made by the Mahoning to the Ohio can not be determined. As has been stated, the Mahoning joins the Beaver a short distance below Youngstown, just east of the boundary line between Pennsylvania and Ohio. It is extremely probable that the Beaver is not polluted to the extent that the Mahoning is, and we may therefore be fairly certain that when the waters of the Mahoning reach the Ohio River their condition is greatly improved.

MUSKINGUM RIVER.

Drainage basin.—The drainage basin of the Muskingum is the largest in Ohio, covering 7,797 square miles. (See fig. 16.) It is formed at Coshocton by the confluence of the Walhonding and Tuscarawas, and from that point flows southward, then southeastward, a distance of 110 miles, entering the Ohio at Marietta. The other important tributaries are Licking River and Wills Creek.

The basin occupies nearly all of the southeastern part of the State, extending from Marietta up to the Lake Erie drainage divide, and from the Scioto Basin on the west to that of the Ohio River on the east. Geologically the basin is made up of two portions—a glaciated and an unglaciated area. The former includes, roughly, the western and northwestern parts of the basin; the latter comprises the remainder. Agriculture flourishes in the glaciated area, where the surface is smooth, rolling, or flat, while mining interests have been developed in the unglaciated part. Many parts of the basin are entirely deforested, yet some sections still bear timber.

Population of basin.—The population of the Muskingum Basin is large, and has been increasing at a rapid rate during the decade ending 1900. According to the Twelfth Census the total population is not far from 750,000, or about 97 per square mile. Of this, the urban population is approximately 200,000, leaving for the rural districts 550,000. These figures, while not exact, represent a careful estimate taken from the Twelfth Census reports.

WALHONDING CREEK.

The Walhonding has its origin in the west-central portion of Richland County. The highest section of the river is known as Black Fork; flowing southeastward it is joined by Rocky Fork and Jerome Fork, and below the confluence of the latter is known as Mohican River. Flowing still farther southeastward it is intercepted by Kokosing River, and from this point to Coshocton the term Walhonding Creek is applied to it.

BLACK FORK.

At the head of Black Fork the basin is a sparsely settled agricultural region, containing only four small hamlets, the largest having not more than 150 inhabitants. Shelby, a growing manufacturing town, having a population of 4,685, is the highest point of appreciable

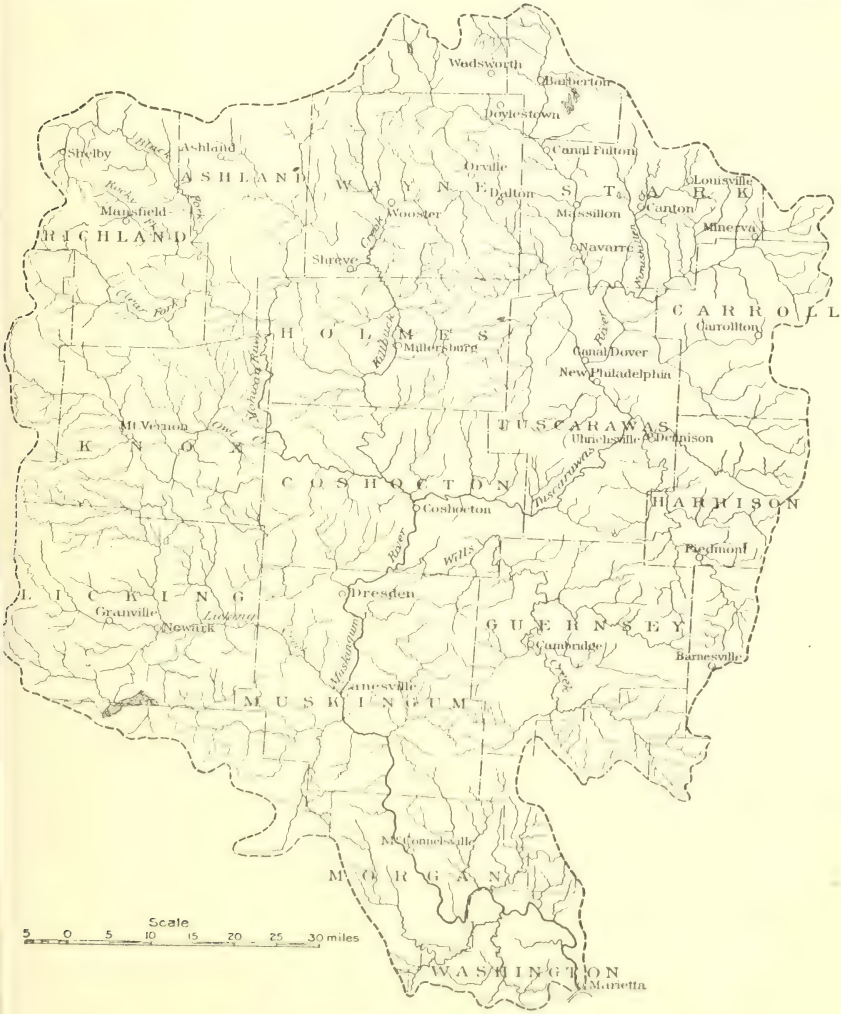

FIG. 16. Muskingum River drainage basin.

ollution. The run-off water from the area above this place is probably nearly normal.

The Ohio State Board of Health has made a faithful survey of the basin, and a series of chemical examinations was made during the spring, summer, and fall of the year 1899. In the published report of this work there appears a series of analyses of samples

of water taken from Black Fork above Shelby, which is reproduced below.

TABLE 97.—*Analyses of water from Black Fork above Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as				Chlorine.	Total residue.	Hardness.		Precipitation, departure from normal for month.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1899.											*Inches.*
May 3	18	w[a]	0.166	0.071	0.008	0.06	4.1	406	197.6	33	2.15
May 29	28	e	.660	.110	.002	.11	Tr.	956	120.8	13.9	----
June 27	25	v	.174	.070	.002	.10	1.5	354	176.8	33.8	-.44
July 18	30	e	.268	.061	.016	.06	.9	407	153.6	84.8	-.29
Aug. 17	20	v	.246	.088	Tr.	.02	4.3	428	191.6	81.6	2.21
Sept. 18	16	v	.166	.053	Tr.	.03	2.1	411	191.4	59.2	+1.31
Oct. 12	25	None.	.146	.033	Tr.	.00	1.3	414	227.4	48.2	+.06
Nov. 17	45	e	.132	.018	.004	.02	1.7	468	181.8	98.6	-1.62
Average	26		.245	.063	.004	.05	2.0	480	180.1	56.6	------

[a] w, woody; e, earthy; v, vegetable.

The results above reported indicate that the water analyzed contained considerable organic matter, which, if we may judge from the conditions existing in the contributing drainage area, is of vegetable origin. The water is not highly colored and there is no indication that pollution exists other than that inevitably arising from decayed vegetation. The free ammonia, nitrites, and chlorine are low; the water contains a comparatively large proportion of alkaline salts which cause a high degree of hardness. It is evident, however, that nearly 75 per cent of these salts are carbonates. In general, the series of analyses is important because it is one of a very few available reports upon a normal or practically normal surface water in the northern drainage basin of the Ohio River.

For purposes of comparison, analyses of water from Black Fork below Shelby were made by the State Board of Health, the samples being collected at the same time as were those reported in Table 97

TABLE 98.—*Analyses of water from Black Fork below Shelby.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Precipitation, departure from normal for month.
1897.										*Inches.*
May 3	12	d [a]	0.238	0.015	0.06	11.7	538	115.8	100.9	−2.15
May 29	32	e	.530	.032	.15	7.8	435	103.0	54.1	
June 27	17	d	.198	.034	.12	12.5	473	137.8	87.0	.44
July 18	60	v	.352	.022	1.25	6.3	383	110.2	88.8	+.29
Aug. 17	20	v	.236	Tr.	.05	28.3	810	57.2	327.6	2.21
Sept. 18	20	Cattle	.442	.002	.06	32.1	959	90.4	350.6	1.31
Oct. 12 [b]	----		----	----	----	--				0.06
Nov. 17	20	m	.100	.014	.06	8.7	598	77.4	225.6	1.62
Average	26	----	.299	.017	.25	15.3	599	98.8	176.4	

[a] d, disagreeable; e, earthy; v, vegetable; m, moldy. [b] No water flowing.

The effect of pollution from Shelby is evident in the analyses above reported. There is a significant rise in the proportions of free ammonia, nitrites, and chlorine, which can be due to nothing else than sewage pollution. It is worthy of note that there is a great change in the character of the alkaline salts contained in the water. The marked decrease in alkalinity, accompanied by the increase in normal hardness, shows that through some influence, probably by the discharge of some chemical at Shelby, the carbonates have been changed to sulphates or chlorides.

Black Fork is joined by Rocky Fork about 30 miles below Shelby, but the intervening country is sparcely settled and there is little further material pollution except that from Richmond County Infirmary.

ROCKY FORK.

The drainage area of Rocky Fork lies in the central part of Richland County, immediately south of that of Black Fork. During past years it has been one of the most grossly polluted streams in Ohio, because of the discharge into it of raw sewage from Mansfield, a city of 17,640 inhabitants. The condition of the stream below this city has been so offensive that it became necessary to establish a system of sewage disposal. The Ohio State Board of Health examined, previous to the installation of this disposal plant, two series of samples of water from Rocky Fork, one of the sampling points being located

above the city and the other below. That part of the drainage area above Mansfield comprises a country richly fertilized for agricultural purposes, and the run-off is therefore not normal for the basin.

TABLE 99.—*Averages of analyses of water from Rocky Fork, above and below Mansfield.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mansfield	20	..	0.282	0.051	0.005	0.08	2.9	512	169.7	59.0	8
Below Mansfield	23	f[a]	.413	.088	.088	.14	16.7	583	146.1	55.5	8

[a] f, fishy.

It is hardly necessary to comment on the contrast offered by the two averages set forth in the above table. The second statement shows an enormous increase in organic matter, in chlorine, and in all other constituents which serve to indicate extensive sewage pollution. It is believed that the river has been improved since the establishment of the Mansfield sewage purification works, but an analytical proof is not at hand.

Between the junction of Rocky Fork and Black Fork and the entrance of Clear Fork is the village of Loudensville, containing 1,500 inhabitants. There is no public water supply or sewerage system, but there is nevertheless considerable drainage into the stream by private sewers, ditches, and gutters.

Clear Fork appears to be a comparatively clean stream, the principal center of population within its drainage area being Belmont, which has a population of 1,039.

JEROME FORK.

At the confluence of Black and Jerome forks is the head of Mohican River. Jerome Fork drains the greater part of Ashland County and the western portion of Wayne County. The only place of importance upon the stream is the city of Ashland, with 4,087 inhabitants, provided with a water supply and sewerage system.

MOHICAN RIVER.

From the above statements, it is clear that the water contributed to Mohican River by the tributaries described is badly polluted and of little value in its raw state as a water supply. The remainder of

the resources vested in the water of this stream are probably not greatly affected by pollution.

OWL CREEK.

Mohican River flows nearly due south to its confluence with Owl Creek, and there are upon its banks no important centers of population. The water flowing in the channel must, therefore, constantly improve in quality. Owl Creek, however, is a different stream; it drains the greater part of Knox County, and extends to the Scioto River divide. The country is level and is a very fertile agricultural region. In the middle of the drainage area is the city of Mount Vernon, having a population of 6,633. It is a rather important manufacturing town, although it has not grown much during the last decade. A water supply and a system of sewerage has been provided, the latter emptying directly into Owl Creek. There is also considerable surface pollution from vaults and cesspools. Above the city of Mount Vernon there are, in Owl Creek Basin, several small villages, which, together with the richly fertilized fields, contribute a sufficient amount of pollution to the river to materially change the quality of the water, which would otherwise be normal.

TABLE 100.—*Averages of analyses of water from Owl Creek above and below Mount Vernon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Mount Vernon	13	o/	0.095	0.036	0.003	0.05	1.2	292	192.0	13.9	8
Below Mount Vernon	14	M	.121	.060	.009	.08	3.1	303	190.7	33.3	8

o/, oily; M, musty.

KILLBUCK CREEK.

Killbuck Creek enters Mohican River a short distance below the mouth of Owl Creek. It drains a large part of Wayne and Holmes counties and a small part of Coshocton County. At the headwaters of this stream is a comparatively large rural population, the principal centers of which are Warsaw and Creston, while the highest town of importance is Wooster, a city of 6,063 inhabitants.

Above Wooster two points were selected by the Ohio State Board of Health for the collection of samples of water for analysis; one in Killbuck Creek, above the mouth of Apple Creek, which flows in at Wooster; one in Apple Creek above Wooster, and the third below Wooster,

the latter representing a mixture of waters from both Killbuck and Apple creeks. Above Wooster on Apple Creek are the Wayne County Childrens' Home and the Wayne County Infirmary, which pollute the water of the stream to some extent. At Wooster are Wayne College and several industrial establishments.

TABLE 101.—*Averages of analyses of water from Apple and Killbuck creeks above Wooster and from Killbuck Creek below Wooster.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Killbuck Creek above Wooster	28	M[a]	0.336	0.112	0.006	0.05	5.4	336	130.1	23.4	8
Apple Creek above Wooster	19	None.	.153	.038	.003	.05	2.6	254	140.2	16.6	8
Killbuck Creek below Wooster	28	M	.322	.165	.022	.09	6.5	359	130.5	28.3	8

[a] M, musty.

Between Wooster and the junction of Killbuck Creek with Walhonding Creek there are numerous small villages, a few being provided with small sewerage systems. It is more than likely that the condition of the water shown in the last analysis in Table 101 is maintained by these small pollution points in practically the same condition as that indicated in the table.

From the mouth of Killbuck Creek it is only a short distance down Walhonding Creek to Coshocton, the head of Muskingum River. The Ohio State Board of Health has made an analysis of the water of Walhonding Creek above Coshocton which shows clearly the character of the water contributed to the Muskingum by the Walhonding Basin.

TUSCARAWAS RIVER.

The basin of the Tuscarawas covers about 2,547 square miles in the northwestern portion of Muskingum watershed. It is the largest tributary of the Muskingum, flowing through a fertile, prosperous country, which has a large population, and is dotted over with rapidly growing municipalities. In the central-southeastern part of the basin coal mining is largely developed, while agriculture is confined in general to the northern and western portions. The river rises in Summit County, and, by a somewhat circuitous route, finally takes a course southwest, flowing through Stark, Tuscarawas, and Coshocton counties, and meets Walhonding Creek at Coshocton to form the Muskingum.

The tributaries of the Tuscarawas are important, and cover diversified portions of the drainage area. Chief among these is Big Stillwater Creek, which flows from the south, through Harrison and Tuscarawas counties, draining an area of 472 square miles. Sugar Creek flows in from the northwest, its basin comprising 356 square miles. Sandy Creek is an important stream which flows in from the east, along the northern part of Carroll and the southern boundary of Stark counties.

HIGHLAND TRIBUTARIES.

Wolfe and Chippewa creeks drain the northernmost portions of the Tuscarawas Basin, comprising parts of Summit, Medina, and Wayne counties. There are numerous small villages in the basin, which have no important influence on the character of the run-off water, although they undoubtedly pollute it to some extent. The first important center of population is Barberton, a comparatively new town, the growth of which has been rapid, by reason of the recent establishment of manufacturing. A system of sewers has been provided, which serves about 3,000 people, and has an outlet in Wolfe Creek. The manufacturing refuse, too, damages the stream to some extent. Wadsworth, Orrville, Dalton, and Doyleston are situated in the drainage area. These municipalities are not important, although from Wadsworth there is considerable contamination of the stream from the salt works established there. Rillman is also an important center of the salt industry, the wastes from which impregnate the whole drainage from this section.

The largest city in the Tuscarawas Basin is Massillon, an important manufacturing place in Stark County, situated a few miles below the confluence of Wolfe and Chippewa creeks, and having a population of 11,944. Refuse from strawboard factories and other manufacturing plants, as well as the sewage from a combined system of sewers, pollutes the stream. The Ohio State Board of Health has made a series of analyses of the water taken from the river above and below Massillon, the average results of which are set forth in Table 102.

TABLE 102.—*Averages of analyses of water of Tuscarawas River above and below Massillon.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Free ammonia.	Nitrogen as— Nitrites.	Nitrogen as— Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Hardness. Normal hardness.	Number of analyses made.
Above Massillon	23	v [a]	0.175	0.060	0.003	0.06	102.8	513	136.8	58.8	8
Below Massillon	29	M	.343	.093	.007	.10	64.5	578	152.0	33.6	8

[a] v, vegetable; M, musty.

In the above analyses the effects of waste from salt works are readily apparent in the high chlorine content. Aside from this, the river shows a high content of organic matter, which, although no records of normal water are available for comparison, seems to indicate pollution from the country above. The average representative analyses of water from the river below Massillon show a characteristic increase in the amount of organic matter, yet the chlorine does not appear to be present in so large proportion as above the city. This is not explained in the last report of the Ohio State Board of Health; it may be due to dilution, as there are two streams entering the river between the sampling point above the city and that below.

SANDY CREEK.

Sandy Creek enters the Tuscarawas a short distance below Massillon, and contributes a considerable amount of pollution from Canton, Wellsville, Minerva, and other small places. Minerva has a population of 1,200 and is situated upon Clear Fork, at the extreme eastern end of the Muskingum Basin.

NIMISHILLEN CREEK.

The principal stream of interest in the Sandy Creek drainage area is a tributary called Nimishillen Creek, which drains the country to the north, including the city of Canton and the village of Louisville. The latter is situated upon the east branch of the creek, has a population of 1,374, and is provided with a public water supply, but no sewers. The east branch runs through Canton and joins the west branch at the lower end of the city. The Ohio State Board of Health has conducted two series of analyses of water from west branch, one above and one below Canton.

TABLE 103.—*Averages of analyses of water from Nimishillen Creek above and below Canton.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses made.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Canton	28	23	v [a]	0.176	0.051	0.006	0.35	2.0	294	150.6	35.1	2,400	8
Below Canton	70	28	M	.446	.741	.039	.30	10.4	343	151.7	50.2	95,000	8

[a] v, vegetable; M, musty.

The contrast presented by the above averages indicates unmistakably the great change in the character of the water after it receives pollution from Canton.

TUSCARAWAS AT CANAL DOVER AND NEW PHILADELPHIA.

Canal Dover and New Philadelphia are cities situated on the opposite sides of Tuscarawas River at the junction of Sugar Creek, a stream which drains a considerable area of country to the northwest. The former city has a population of 5,422; the latter contains 6,213 inhabitants. Both are important manufacturing places, and their industrial plants contribute a large amount of foul matter to the river. Canal Dover has no sewerage system at present, but the drainage into the river is nevertheless extensive. New Philadelphia has an excellent sewerage system, which discharges into the river. We have, then, at this point a combined population of 11,635, the wastes from which have an important effect on the quality of the Tuscarawas River.

TABLE 104.—*Averages of analyses of water from Tuscarawas River above Canal Dover and below New Philadelphia.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Canal Dover	23	e a	0.227	0.062	0.005	0.07	23.9	369	112.8	39.3	8
Below New Philadelphia	24	e a	.237	.060	.005	.10	23.4	343	107.4	36.2	8

a e, earthy.

Comparison of the results of analyses from the two points above stated shows that the water in Tuscarawas River is not materially changed after receiving the pollution from Canal Dover and New Philadelphia. It is probable that the amounts of nitrogen and of chlorine are practically the same, and that the color, turbidity, and odor do not differ widely. The reason for this is not far to seek. Examination of the map will show that between the sampling point above Canal Dover and that below New Philadelphia three tributaries enter—Sugar Creek, Stone Creek, and Oldtown Creek. The first of these tributaries drains an area of 356 square miles; the other two have basins considerably smaller. The water flowing from these tributaries is not polluted to any significant extent, and it is reasonable to believe that the large measure of dilution, which must, of necessity, arise, is sufficient to account for the lack of material difference in the character of the water as shown by analyses at the two sampling

points. The quantitative determinations of bacteria made by the State Board of Health, however, tell another story. It has also been remarked that the differences between gelatin culture media manufactured in different laboratories are often the cause of varying results in determining the number of bacteria, so that when the same water is tested the number of bacteria found in different cases varies widely. Therefore little value can be given to quantitative determinations, unless numbers vary to such an extent that the difference between one and the other is greater than any possible error introduced by the discrepancy in the work. In the report of the Ohio State Board of Health, above referred to, the average number of bacteria per cubic centimeter above Canal Dover is 2,350, and below New Philadelphia 6,200, a difference so wide that it can not be reasonably accounted for by variations which might be introduced into the work by the use of nonuniform culture media. The media used in these determinations were all made in the same laboratory and, presumably, after the same methods, so that it is probable that the above-described variation would not occur. The fact that there are so many more bacteria in the water below New Philadelphia than above Canal Dover arises unquestionably from the difference in the character of the organic matter. In other words, the fact that there is sufficient organic matter of a certain kind in the water at the lower sampling station to provide food for 6,200 bacteria, while at the upper station it is suffi ient in amount to provide food for only 2,350, shows that the character of the organic matter has been seriously changed, even though the large degree of dilution arising from the cause above stated preserves the proportionate amounts practically the same.

STILLWATER CREEK.

After proceeding down Tuscarawas River for 5 or 6 miles one comes upon the confluence of Stillwater Creek. This stream has a drainage area of 472 square miles, lying principally in Harrison, Belmont and Tuscarawas counties. The river forks a few miles from this confluence with the Tuscarawas, and thereafter the northernmost branch is called Little Stillwater Creek, while that immediately to the south is known as Big Stillwater Creek. The pollution in the basin of Little Stillwater Creek is not extensive, while in the upper part of the Big Stillwater Basin there are only a few small centers of population, such as Barnesville, Piedmont, and Freeport. At the junction of the two forks are situated the municipalities of Uhrichsville and Dennison.

The following statement of averages of analyses of water above Uhrichsville and below Dennison are taken from the report of the Ohio State Board of Health, above referred to.

TABLE 105.—*Averages of analyses of water from Stillwater Creek above Uhrichsville and below Uhrichsville and Dennison.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Number of analyses made.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Uhrichsville	25	M[a]	0.287	0.089	0.007	0.07	4.5	344	114.1	17.8	8
Below Uhrichsville and Dennison	25	M	.288	.188	.007	.17	7.1	376	98.8	40.2	8

[a] M, musty.

The evidences of increase in pollution appearing in the two averages above referred to are easily appreciable, notably by the rise in free ammonia and chlorine.

Below the mouth of Stillwater Creek, in the course of the 40 miles which intervene between that point and the head of Muskingum River, small villages are situated upon the banks of the stream, containing the usual number of industries, but the only important center of pollution is Newcomerstown, which has, according to the Twelfth Census report, 2,659 inhabitants.

MUSKINGUM RIVER BELOW COSHOCTON.

Walhonding Creek and Tuscarawas River are further polluted at their confluence by drainage from the city of Coshocton, which has a population of 6,473. Along the water front of this city are located important manufacturing plants, which pour their wastes into the stream. The city is provided with a water supply and sewerage system, and the sewage, together with that carried by surface drains, as well as the town garbage, is poured into the river. There arises, therefore, at this point an important contamination, which is said to be offensive during periods of low water. Three series of analyses have been carried on at Coshocton by the Ohio State Board of Health. The sampling points chosen were Walhonding Creek and Tuscarawas River, both above the confluence of Coshocton pollution, and a point on Muskingum River at a proper distance below the confluence of the two main tributaries where it was reasonably certain that the waters of the two streams and the pollution from Coshocton were thoroughly mixed.

TABLE 106.—*Averages of analyses of water from Walhonding Creek and Tuscarawas River above Coshocton and from Muskingum River below Coshocton.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Number of analyses made.
Walhonding Creek above Coshocton	...	21	e[a]	0.187	0.045	0.004	0.10	5.4	303	139.0	14.4	8
Tuscarawas River above Coshocton	...	16	...	.128	.028	.003	.05	20.6	303	119.0	29.1	8
Muskingum River below Coshocton	113	20	...	.180	.043	.005	.05	19.4	329	120.4	49.2	8

[a] e, earthy.

Comparison of the analyses of water from Walhonding Creek above Coshocton with those of water from Tuscarawas River shows that the latter is not so highly colored. The amount of residue is the same as in the Tuscarawas, the alkalinity higher, but the normal hardness less. It is notable that the content of chlorine in the Tuscarawas is higher, the difference being due principally to contamination from the salt works in the upper part of the basin of that tributary. The Walhonding has more organic matter than the Tuscarawas. In both streams the water is greatly damaged by pollution, but the nuisance occasioned thereby is not general, being confined to certain localities near points of discharge of certain city sewers.

WILLS CREEK.

Wills Creek enters the Muskingum from the east a short distance below Coshocton. It is the drainage outlet of Guernsey County, and the basin comprises also small areas in Noble and Belmont counties. The creek is formed by the confluence of Buffalo Fork and Seneca Falls Creek a short distance north of Noble County line, and pursues an extremely winding course to its outlet, running through Guernsey, Coshocton, and Muskingum counties and into the Muskingum River. The only considerable center of population in the drainage area is Cambridge, a city of 8,241 inhabitants. This is an important coal-distributing point, and it contains tin and iron mills, which contribute considerable amounts of wastes to the river. Sewers have been introduced at Cambridge and, although they have not been widely extended, they do their full measure of damage to the stream. Leatherwood Creek, which enters Wills Creek at Cambridge, drains an important mining district and, as a result, is very turbid by reason of a large amount of coal-mine waste.

The Ohio State Board of Health has conducted a series of analyses of water above and below Cambridge on Wills Creek. That above Cambridge is not representative of the character of Leatherwood Creek water.

TABLE 107.—*Averages of analyses of water from Wills Creek above and below Cambridge.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Number of analyses made.
Above Cambridge	784	23	v[a]	0.227	0.109	0.017	0.12	26.6	471	136.8	40.7	8
Below Cambridge	464	24	M	.235	.204	.025	.14	10.0	352	92.5	65.6	8

[a] v, vegetable; M, musty.

The results above set forth indicate a considerable rise in free ammonia, nitrites, and chlorine after the water passes Cambridge. Mr. Benjamin H. Flynn, engineer of the Ohio State Board of Health, is of the opinion that there is not sufficient discharge of sewage from Cambridge to account for so great a rise in the constituents indicating sewage pollution, and that the change is probably due to industrial wastes. The reduction in the amount of turbidity is interesting, as it indicates a possible discharge of coagulating material from the mines, probably sulphate of iron. To this extent, therefore, the industrial pollution may be regarded as a benefit.

LICKING CREEK.

About 20 miles below the confluence of Wills Creek is the city of Zanesville, at which point Licking Creek joins the Muskingum. This stream drains the north of Licking County and part of Knox, Perry, and Muskingum counties. The western part of this basin is level and is devoted to agriculture, while the eastern part is hilly. At the headwaters of the stream are many small towns, the principal ones being Centerburg, Utica, Pataskola, Johnstown, and Granville, having a combined population of 4,270.

Newark, with a population of 18,157, is the commercial center of the basin. It contains many manufacturing industries and several slaughter houses, and these, together with the city sewage, make the river very foul at times.

Analyses of water from Licking Creek above Newark indicate that it is rich in organic matter, yet there is no special evidence of dangerous contamination, while the samples taken from the stream below Newark present the usual contrast.

TABLE 108.—*Averages of analyses of water from Licking Creek above and below Newark.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.	Number of analyses made.
Above Newark	87	13	None.	0.106	0.029	0.002	0.04	1.6	309	184.0	21.3	700	8
Below Newark	99	14	M[a]	.162	.088	.006	.07	3.0	329	181.4	13.4	5,200	8

[a] M, musty.

The city of Zanesville, with population of 23,538, is the largest center of pollution yet considered in the drainage basin of the Muskingum. The water supply is taken from Muskingum River just above the city, but the water is so impure that steps are now being taken to improve its quality or to procure another source of supply. A sewerage system has been provided, and the manufacturing industries are important. In addition to the contamination from sewers and from these manufacturing plants, the river receives sewerage drainage, which is dangerously polluted by slovenly methods of disposing of garbage and night soil.

The Ohio State Board of Health has conducted three series of examinations, eight samples being taken from each of the following points: Muskingum River above Zanesville, Licking Creek above Zanesville, and Muskingum River below Zanesville. The averages of the results of these examinations are reproduced below.

TABLE 109.—*Average results of analyses of water from Licking Creek above Zanesvile and from Muskingum River above and below Zanesville.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.	Number of analyses.
Licking Creek above Zanesville	15	0.288	0.059	0.006	0.05	3.2	510	165.3	21.4	2,700	8
Muskingum River above Zanesville	25	.285	.063	.006	.08	10.0	498	114.2	35.9	2,700	8
Muskingum River below Zanesville	24	.324	.098	.009	.08	9.6	530	118.7	23.4	12,000	8

There is a striking similarity in the analyses of the waters from Muskingum River and from Licking Creek above Zanesville. In fact,

the determinations practically conform, the only significant departure being in the case of chlorine. In the preceding pages it has been noted that salt works contributed large quantities of waste to the Tuscarawas River, which results in raising the amount of chlorine to a height unwarranted by existing sewage pollution. To this is probably due a part of the excess of chlorine in water in Muskingum River above Zanesville over that in Licking Creek.

In the introduction to this paper it was stated that the chlorine contributed to surface water does not undergo mechanical change similar to that which takes place in the nitrogen compounds, but firmly maintains its identity, fluctuating in amount according to the dilution which it receives from tributaries, or the contributions from sewers and other polluting factors, and when organic matter is completely changed to inorganic compounds, and all other trace of contamination is lost, the chlorine remains an unshaken witness of past pollution. We have also seen in the pages immediately preceding that large amounts of sewage are poured into the streams in the Muskingum Basin. By the time the water reaches Zanesville the organic matter poured in from the cities in the upper part of the basin has been nearly or completely consumed, and that which appears on analysis is undoubtedly of recent origin. But the chlorine in the Muskingum, which is in so great excess over that in Licking Creek, is largely the evidence of pollution both from sewage and from the salt works in the upper part of the basin.

The condition of the water of Licking Creek is so similar to that of Muskingum that it can not be said that either stream is a detriment or a benefit to the other. In the one case we have a water recently polluted, while in the other it appears that the water was at one time more seriously contaminated, but through the effects of oxidation, sedimentation, and dilution the evidences of this contamination have been nearly lost, and the most apparent pollution is that derived from sources not far above Zanesville.

Analyses of the water of the Muskingum below Zanesville show, in a fairly satisfactory manner, the effect of the commingling of the waters of Licking Creek and Muskingum River in conjunction with the wastes of Zanesville.

Below Zanesville, on the Muskingum and on the minor tributaries, there are a number of small towns which, while collectively they contribute some foreign matter, do not influence the character of the water extensively. There is no place of importance until McConnelsville is reached, the county seat of Morgan County, containing 1,825 inhabitants, and provided with water supply and sewers. Just above this place the Ohio State Board of Health has taken a series of samples for examination, the results of which are embraced in the following table.

TABLE 110.—*Analyses of water from Muskingum River above McConnelsville.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.
1899.												
April 28	35	10	None.	0.178	0.038	0.004	0.08	5.8	269	101.1	56.8	350
May 24	271	28	e[a]	.234	.060	.007	.08	3.8	304	73.0	50.0	1,400
June 22	(b)	20	e	1.064	.152	.003	.13	2.1	1,784	44.5	7.6	7,000
July 25	205	...	v	.230	.058	.009	.26	11.8	296	90.8	21.8	1,400
August 30	114	22	v	.228	.156	.018	.04	14.8	329	147.2	40.0	1,400
September 27	65	20	e	.164	.046	.012	.10	14.3	306	152.2	None.	420
October 17	52	10	v, e	.140	.028	.015	.06	15.7	308	152.2	31.8	370
November 22	52	20	None.	.162	.034	.004	.11	19.0	315	142.2	49.0	420
Average	...	19	.....	.300	.075	.009	.11	10.9	489	112.9	32.1	1,600

[a] e, earthy; v, vegetable. [b] Enormous.

From McConnelsville to Marietta, at the mouth of the river, there are the usual number of small villages, the effects of which upon the character of the water are not important. Marietta, with population of 13,384, has considerable manufacturing and a public water supply and sewerage system, which empties into Ohio River, so that it has no effect on the Muskingum. There is, however, considerable manufacturing sewage poured into the latter.

TABLE 111.—*Analyses of water from Muskingum River above Marietta.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.
1899.												
April 28	52	10	p[a]	0.102	0.356	0.002	0.10	5.7	275	112.4	57.9	350
May 24	600	25	e	.216	.046	.009	.09	2.9	396	71.8	22.4	550
June 22	(b)	22	e	.464	.136	.004	.12	9.3	1,017	93.9	52.0	3,900
July 25	210	28	v	.296	.066	.008	.05	8.2	234	93.6	17.0	600
August 30	80	20	e	.202	.052	.012	.04	8.9	245	122.2	55.0	170
September 27	80	25	e	.158	.022	.010	.05	13.5	304	143.6	6.4	300
October 17	110	10	m	.120	.016	.008	.03	11.2	300	146.8	62.0	275
November 22	49	10	None.	.112	.016	.004	.16	17.9	322	144.2	39.4	1,700
Average	.....	19		.209	.050	.007	.08	9.7	390	116.1	39.0	1,000

[a] p, peaty; e, earthy; v, vegetable; m, moldy. [b] Enormous.

The above analyses show fairly well the character of the water contributed to the Ohio system from the Muskingum Basin. The water

improves in quality between Zanesville and the mouth of the river, and therefore the effect of the Muskingum system on the Ohio is less damaging than might be supposed after considering the points of pollution in the Muskingum.

The analyses given certainly show that the Muskingum is in many places a very foul stream. Indeed, there are few points at which water can be collected in its normal and undamaged state. This stream is certainly not a proper one to use as a sewage course, for its greatest value is in its water resources. It is not good for much as a source of power, its navigation is insignificant, and the humid climate of the country makes its use for irrigation unnecessary. There are, perhaps, certain points along the course of the stream which are fit places for the harvesting of an ice crop, but the Muskingum can never be an extensive ice field. Therefore the water-supply value of the river is practically the only important one, and, as has been shown, this is greatly damaged. It is unwise to utilize for domestic purposes the waters of the Muskingum and its tributaries at almost any point unless efficient means of purification are adopted. On the other hand, the character of the river basin is such that self-purification readily takes place. There is no doubt that if means were used to purify the sewage which is now poured into the stream, the waters could, in certain places, be used as a water supply without any treatment.

SCIOTO RIVER.

DRAINAGE BASIN.

The drainage basin of Scioto River occupies a long, narrow strip of country in the central and southern part of Ohio, extending from the Lake Erie drainage divide on the north to the Ohio River at Portsmouth on the south, and comprising about 6,400 square miles. The source of the river is in Auglaize County, in a portion of the drainage area which juts westward and lies north of the Great Miami Basin. Thence it runs in a generally southerly direction 40 miles, to a point a little southwest of the city of Marion. The fall along this section is nearly 500 feet. Thence its course is almost due south. It passes through the city of Columbus, capital of the State of Ohio, the fall from Marion to this point being 430 feet. Continuing south, the river joins the Ohio at Portsmouth, 110 miles above Cincinnati. The fall of the river between Columbus and Portsmouth averages 26 feet per mile along the entire length of 130 miles. The entire course of the river, measured in a straight line, is 175 miles, although when actually traversed it amounts to nearly 210 miles.

The tributaries are not so large nor so important in this drainage area as they are in the Muskingum, by reason of the fact that the watershed is somewhat narrow. The most important tributaries and the area drained by them are named below.

TABLE 112.—*Drainage area of Scioto River and tributaries.*

	Sq. miles.
Olentangy River at mouth at Columbus	547
Big Walnut Creek at mouth	513
Darby Creek at mouth	592
North Fork of Paint Creek	236
Main Fork of Paint Creek above junction with North Fork	828
Paint Creek at mouth	1,083
Scioto River at southern boundary of Marion County	628
Scioto River at Columbus, above junction with Olentangy River	1,139
Scioto River at Columbus, below junction with Olentangy River	1,686
Scioto River at Circleville and Darby creeks	3,275
Scioto River at Chillicothe	3,923
Scioto River at mouth	6,400

The principal economic value of Scioto River lies in its availability as a source of water supply. It is not an important power stream, although in past years the aggregate of power developed by the numerous plants along it was fairly large, but on account of the flatness of the area there is not sufficient opportunity to develop many or extensive power sites, those which have been utilized being of the capacity which are found necessary to the development of saw and grist mills only. The development of cheaper power in other parts of the country and the improvement of transportation facilities have led to the abandonment of a large number of the power privileges afforded by the Scioto, and very few of those that remain are of much value. Even as a source of water supply the opportunities for conservation are not all that could be desired, for it is necessary in some places to pump the water directly from the flowing stream into distributing reservoirs, the storage capacity of which is not in every case sufficient to allow the water to be properly stored and purified. This condition aggravates the dangers due to polluted river water, for under these circumstances pollution becomes more certain in its unfavorable effects upon the water consumer than it could be if a longer term of storage were afforded.

NORMAL WATER IN THE SCIOTO BASIN.

There are no public records of analyses of a distinctively normal water in the Scioto Basin. The work of the Ohio State Board of Health has so far been confined almost entirely to the examination of polluted streams, and it is only from the series of analyses made near the headwaters of the rivers and above the highest points of appreciable sewage pollution that we are able to obtain any ideas concerning the character of these waters in their normal state. In the basin of the Scioto it is probable that the analysis affording the best idea of the character of its normal water is that which has been made of samples collected above the city of Kenton, in Harding County. The population above the city is almost entirely rural, there being a few small villages, containing from 25 to 100 inhabitants, and while the

contamination which they impart to the headwaters of the Scioto is hardly appreciable, yet it can not be said that the water which reaches Kenton is normal. It is probably nearly so, and for all practical purposes can be so considered. The analyses of this water appear in the following table:

TABLE 113.—*Analyses of water from the Scioto River above Kenton.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 12	4	None.	0.514	0.062	0.024	1.50	2.0	730	210	226	1,300
July 16	4	e [a]	.462	.098	.003	.42	1.0	805	232		480
August 25	2	None.	.292	.084	.000	.00	2.5	625	234	130	430
September 25	4	e	.238	.028	.000	.00	3.8	670	226	122	270
October 23	3	M	.240	.030	.000	.00	3.3	605	252	112	390
December 1	5	M	.638	.571	.030	9.38	1.5	1,075	104	510	1,900
Average	4		.379	.145	.010	1.900	2.3	752	210	183	790

[a] e, earthy; M, musty.

POLLUTION IN BASIN OF THE SCIOTO.

Kenton is a city of 6,852 inhabitants, provided with sanitary sewers and storm-water drains. Both systems discharge into the river. The effect upon the water is easily appreciable upon examination of the following table:

TABLE 114.—*Analyses of water from the Scioto River below Kenton.*

[Parts per million.]

Date of collection.	Color.	Nitrogen as				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.										
June 12	4.5	0.430	0.142	0.026	1.60	4.0	710	244	228	
July 16	3.0	1.720	.476	.000	.00	4.5	720	32		5,800
August 25	2.0	1.328	.384	.010	.00	6.5	605	232	118	2,400
September 25	3.5	.360	.764	.003	.00	12.5	645	238	114	4,200
October 23	3.0	.588	2.160	.005	.00	18.0	650	258	114	17,000
December 1	5.0	.624	.584	.030	.44	2.0	975	118	466	14,000
Average	3.5	.841	.751	.012		7.9	718	182	173	8,700

Continuing down the Scioto no further important source of pollution is met with until the mouth of Little Scioto River is reached. In the drainage area of this river is the city of Marion, containing, according to the Twelfth Census, 11,862 inhabitants. Sewer outlets enter the river a short distance above its confluence with the Scioto, and there are published records of analyses of the water from Little Scioto, above and below the sewer outfall, which are reproduced in Table 115.

TABLE 115.—*Analyses of water from Little Scioto River above and below the Marion sewers' outfall.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above Marion	3	0.489	0.378	0.013	1.25	5.3	469	204	75	8,200	6
Below Marion	3	.464	1.897	.037	1.31	16.5	553	231	85	9,500	6

The report of the analyses of water from Little Scioto River, taken below the Marion sewer outlets, shows clearly the foulness of the contribution which the system receives from this tributary.

The next point of examination of the Scioto below the confluence of Little Scioto is the Ohio Girls' Industrial Home, which contains a population of over 400. A complete system of sewers is here provided, the wastes from which are poured directly into the river. Table 116 shows clearly the effects of this contamination upon the stream.

TABLE 116.—*Analyses of water from Scioto River above and below the Ohio Girls' Industrial Home.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.	Number of analyses constituting average.
		Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
Above industrial home	3.0	0.334	0.086	0.008	0.176	6.6	509	175	123	1,600	3
Below industrial home	3.0	.320	.103	.009	.206	7.5	507	173	126	1,600	5

The next important center of pollution is the city of Columbus, where enters Olentangy River, the largest stream tributary to the Scioto. Above the confluence of these two rivers the State Board of Health has made three series of examinations, one at Wyandot Grove, above Columbus pollution, another about 3 miles below at Jones's dam, where the city's sewage begins to have effect; and a third at Sandusky street bridge, near the mouth of the Olentangy. The results of this interesting series of examinations appear below.

TABLE 117.—*Analyses of water from the Scioto River at Wyandot Grove.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	s[a]	0.260	0.040	0.002	0.200	4.0	445	194	52	730
July 17	3.0		.378	.028	.002	.170	5.5	500	182	94	910
August 23	2.0	None.	.344	.096	.003	.030	3.8	440	172	88	290
September 23	1.5	e	.316	.098	.002	.030	7.8	550	176	126	300
October 21	2.0	e	.268	.048	.002	.050	7.7	585	200	140	200
December 3	5.0	e	.366	.100	.020	6.300	1.5	467	146	132	2,000
Average	2.5		.322	.068	.005	1.150	5.0	498	178	105	740

[a] s, sweetish; e, earthy.

TABLE 118.—*Analyses of water from Scioto River at Jones's dam.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 23	2	None.	0.276	0.037	0.002	0.340	4.5	455	194	48	810
July 17	3	None.	.398	.028	.003	.200	3.8	510	184	104	400
Aug. 23	2	m[a]	.380	.092	.003	.080	4.1	450	178	80	590
Sept. 23	2	e	.306	.088	.003	.000	7.3	510	176	116	350
Oct. 21	2	e	.296	.082	.006	.050	7.4	454	192	124	700
Dec. 3	5	e	.354	.102	.025	6.500	1.7	464	140	136	2,200
Average	3		.335	.071	.007	1.20	4.8	489	177	101	840

[a] m, moldy; e, earthy.

TABLE 119.—*Analyses of water from Scioto River at Sandusky street bridge.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.
1898.											
June 13	2.0	None.	0.342	0.110	0.007	0.320	7.0	480	190	62	1,470
July 17	3.0	M[a]	.376	.048	.002	.260	4.0	480	184	92	1,030
Aug. 23	2.0	M	.394	.200	.015	.070	10.1	445	180	78	4,540
Sept. 23	2.0	M	.420	.280	.005	.000	11.5	460	152	106	10,800
Oct. 21	1.5	d	.392	.086	.004	.040	8.7	525	158	98	1,150
Dec. 3	6.0	d	.418	.110	.025	5.820	2.3	474	144	136	10,200
Average	2.5		.390	.139	.010	1.090	7.2	477	168	95	4,900

[a] M, musty; d, disagreeable.

OLENTANGY RIVER.

The Olentangy drains an extremely narrow basin lying east of and running parallel throughout the greater part of its length to the middle section of the main river. It rises in the northern part of Morrow County and flows for a short distance northwestward into Crawford County, passing the city of Galion, whence it takes a southerly course, running within 5 miles of the city of Marion, and after flowing through Delaware County and past the city of Delaware enters the Scioto at Columbus.

The highest point of pollution on Olentangy River is Galion, a city of 7,282 inhabitants. The population above this city is sparse, and the water in the river is therefore nearly normal. The State Board of Health conducted in the year 1898 a series of analyses of the water in the river above and below the outlet of Galion sewers, the average results of which appear below in Table 120. As the analyses indicate, the effect of Galion sewage on the river is marked.

TABLE 120.—*Analyses of water from Olentangy River above and below Galion.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.	Number of analyses constituting average.
Above Galion	3.5	M[a]	0.476	0.132	0.007	0.640	8.3	463	206	69	450	5
Below Galion	3.5	M	.994	4.696	.111	.640	50.7	873	262	190	49,000	5

[a] M, musty.

The point of pollution worthy of consideration next below Galion is Delaware, the largest city in and the county seat of Delaware County. Many tributaries enter the river between these two cities, so that the stream is many times larger at Delaware than it is 40 miles above, at Galion. The water in the river above Delaware is markedly improved, as might be expected, but after receiving the contents of the city sewers the conditions are again undesirable, as shown in the following table:

TABLE 121.—*Analyses of water from Olentangy River above and below Delaware.*

[Parts per million.]

Place of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c.c.	Number of analyses constituting average.
Above Delaware	3.5	M[a]	0.322	0.073	0.004	0.860	2.5	408	186	61	1,030	6
Below Delaware	3.5	M	.357	.118	.017	.810	14.5	484	188	96	1,130	6

[a] M, musty.

There are of public record two series of analyses in the lower part of Olentangy River. The sampling point at Olentangy Park is above the serious pollution of Columbus, while the other is at Dublin Bridge, in the city of Columbus, just above the confluence of the Olentangy and Scioto rivers.

TABLE 122.—*Analyses of water from Olentangy River at Olentangy Park.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c.c.
1898.											
July 16	3.0	e[a]	0.426	0.062	0.003	0.240	3.0	390	178	50	680
Aug. 24	2.5	None.	.334	.094	.003	.050	5.8	450	206	74	700
Sept. 23	3.0	e	.354	.076	.002	.000	10.2	555	204	134	400
Oct. 21	2.0	e	.286	.072	.005	.120	7.7	620	226	122	280
Dec. 3	5.0	e	.362	.066	.020	4.950	3.0	404	126	98	1,800
Average	3.0		.353	.074	.007	1.070	5.9	484	188	96	770

[a] e, earthy.

TABLE 123.—*Analyses of water of Olentangy River at Dublin bridge, Columbus.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1898.											
June 13	2.0	e[a]	0.294	0.066	0.011	0.210	5.5	415	202	48	1,150
July 17	3.0	..	.388	.058	.004	.320	3.2	360	166	44	1,600
Aug. 23	2.0	M	.302	.096	.002	.020	5.4	440	194	72	2,100
Sept. 23	2.0	M	.352	.126	.001	.000	8.5	525	192	110	770
Oct. 21	1.5	M	.294	.036	.002	.000	8.7	585	218	112	520
Dec. 3	10.0	M	.372	.074	.020	4.800	3.0	387	132	96	4,000
Average	3.4	..	.334	.076	.007	.890	5.7	452	184	80	1,700

[a] e, earthy; M, musty.

The analyses in Table 123 show the character of the water contributed to the Scioto system by its main tributary. Comparison of the various tables of analyses of the water of the Olentangy will show that at the mouth of the river the condition of the water is far better than it is below Galion, near its headwaters. Along the lower length of the river, however, the water is highly polluted and is unfit for use as a public supply without purification. The other values of the river are not seriously impaired, but as its resources are confined almost entirely to those of water supply, there is little that remains as available assets.

Below the confluence of the Scioto and the Olentangy the bed of the main river is very flat, so that it becomes in places almost a slack-water stream. The storage advantages are thus increased, and the river has remarkable self-purifying powers. Below Columbus the first sampling point is Frank road bridge, which is situated well down toward the lower part of the city. Analyses of the water taken at this point show the effect of the mixture of the upper Scioto and Olentangy waters and the sewage from Columbus.

TABLE 124.—*Analyses of water from the Scioto River at Frank road bridge, Columbus.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.
1897.											
June 11	2.0	d[a]	1.130	2.322	.....	0.030	16.0	495	238	86	8,900
July 17	4.0	d	.896	1.644	0.188	.000	13.0	440	182	84	64,000
August 23	4.0	d	1.136	3.824	.000	.000	21.0	520	256	94	195,000
September 23	3.0	d	.876	7.600	.....	.000	39.0	680	330	112	250,000
October 21	5.0	d	2.340	10.170	.000	.000	41.5	765	346	92	183,000
December 4	4.0	o	.780	.880	.070	4.420	6.0	472	160	134	135,000
Average	4.0	....	1.193	4.406	.043	.74	22.7	562	252	100	140,000

[a] d, disagreeable; o, oily.

Seven miles below Frank road bridge is Shadeville bridge, at which a series of analyses was made, the average results of which are reproduced in the table below:

TABLE 125.—*Analyses of water from the Scioto River at Shadeville bridge.*

[Parts per million.]

Place of collection.	Color.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per c. c.	Number of analyses contributing to average.
Shadeville bridge	3.5	0.806	3.352	0.121	0.121	19.3	510	285	74	7,200	5

Circleville is a village of 6,991 inhabitants, situated near the central part of Pickaway County, about 30 miles below Columbus. A series of examinations made of the river water taken at Main street bridge has been made by the State Board of Health, the reports of which are set forth in Table 126.

TABLE 126.—*Analyses of water from the Scioto River at Circleville.*

[Parts per million.]

Date of collection.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per c. c.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
1897.											
July 22	10.0	e[a]	0.660	0.118	0.030	1.13	1.7	285	114	54	14,000
Aug. 26	2.0		.378	.352	.023	.16	5.5	395	228	20	600
Sept. 27	1.5	e	.320	.210	.007	.....	11.7	400	242	28	500
Oct. 25	2.5	M	.314	.534	.045	.13	11.2	435	282	28	800
Dec. 4	5.0	M	.424	.344	.050	2.68	2.5	393	144	76	3,500
Average	4.0	.....	.419	.312	.031	.82	6.5	382	202	41	3,900

[a] e, earthy; M, musty.

It will be seen that the water at Circleville has been purified to a considerable extent in its course from Columbus down. Free ammonia, nitrites, and chlorine, the standard indicators of sewage pollution in water, are very much reduced, and the analyses at the lower point indicate better conditions.

The only important point of pollution below Circleville is the city of Chillicothe, containing 12,975 inhabitants. No analyses of water taken below this place are recorded. Sixty miles below Chillicothe the river enters the Ohio at Portsmouth.

Little remains to be said concerning the Scioto. The conditions of the river are wholly favorable to the purification of foreign matters that are poured into it, but the raw sewage it receives from the various cities constitutes a source of contamination that can not be overcome. The river is little more than a dumping ground for refuse, and its misuse affords a good example of the wanton destruction of a valuable resource; but the work of the State Board of Health of Ohio bids fair to be fruitful, so that we may confidently expect great improvements in sanitation in the Scioto Valley.

OHIO RIVER AT CINCINNATI.

On Ohio River, below the mouth of the Scioto, a series of notable investigations has been made by Mr. George W. Fuller, following his work on the water supplies of Louisville and Cincinnati, and the reports of these inquiries are probably the ablest that have been presented on the subject in this country. The Cincinnati report, in a concise, definite, and methodical manner, gives just the facts necessary to the discussion, and shows the character of the water of the Ohio as it comes down to Cincinnati, bearing traces of all the pollution heretofore considered, as well as a large amount derived from tributaries that have not yet been investigated, or the investigations of which are not of public record. Therefore one can arrive at an

understanding of the character of the Ohio River at this point no better than by consulting the above-mentioned report, parts of which are, for convenience, here reproduced.[a]

At the outset it is imperative, for a clear understanding of this report, that there should be fixed in mind the two most characteristic features of the local river water, as follows:

1. The wide range in the amount of suspended matter present in the water.
2. The great variations in the nature of the suspended matter, and especially in the size of the particles.

A comprehensive idea of the amounts of suspended matter found at different times in this water during the year 1898 is shown in the following summary:

TABLE 127.—*Turbidity of Ohio River water.*

[Parts per million.]

Number of days, 1898.	Corresponding range of suspended matter.	Number of days, 1898.	Corresponding range of suspended matter.
0	([a])	29	501–1,000
41	11–50	5	1,001–2,000
63	51–100	1	([b])
127	101–250	Average	230
99	251–500		

[a] Less than 10. [b] Over 2,000.

The great variation in the character and size of the suspended matters is best illustrated by the following table, in which there is indicated the different hydraulic subsiding values (or sizes) of two extreme types of the river water. Type I is characteristic of the water during the early portion of a heavy freshet, when it is heavily laden with silt and fairly coarse clay, and Type II is representative of the water during later portions of rises, while it is charged to a greater relative degree with very fine, minute particles of clay.

TABLE 128.—*Periods of subsidence necessary with water from Ohio River at Louisville, Ky.*

Period of subsidence (hours).	Suspended matter in parts per million.		Per cent removed.	
	Type I.	Type II.	Type I.	Type II.
0	2,333	205	0	0
1	932	81	60	55
3	653	80	72	56
6	396	79	83	56
2	350	73	85	58
4	300	61	87	63
8	259	44	89	67
2	210	36	91	70
6	186	31	92	72

Between Types I and II there are found in the course of a year an almost endless number of intermediate combinations.

* * * * * * *

The direct causes of these variations in the Ohio River water are the rises or freshets which are so characteristic of this stream. Indirectly there are a number

[a] Report on investigations into the purification of the Ohio River water, 1899, p. 9 et seq.

of factors which exert much influence. Among them are the amount, rate, distribution, and frequency of the rainfall in the valley, and also the surface geology topography, area, and length of the watershed, and the condition of the soil at the time of heavy rains. To solve the problem of establishing the relation between the composition of this river water and the factors affecting it is a complex matter and so far as our knowledge goes there are available no adequate data for the purpose, nor are such data being obtained.

* * * * * * *

The watershed of the Ohio River above the intake of the new Cincinnati water works at California has an area of about 70,600 square miles. This area includes portions of the States of Ohio, New York, Pennsylvania, Virginia, North Carolina, West Virginia, and Kentucky.

Above the intake of the Front street pumping station (used during these tests) the area of the watershed is estimated at 72,400 square miles. In addition to the area at the new intake the last area includes that of the watershed of the Little Miami River, and that of the Ohio River itself between the Little Miami and the Front street intake, a distance of about 6 miles.

About half a mile downstream from the Front street intake the Licking River empties into the Ohio River on the Kentucky side. At this point the normal width of the river is about 1,000 feet. The Front street intake is situated about 200 feet from the Ohio shore, and in a straight line is distant about 4,000 feet from the mouth of the Licking. Under some conditions of river stages and of wind storms the waters of the Licking reach the Front street intake.

The Licking River has a watershed of about 3,300 square miles. Adding this to the above, there is obtained 75,700 square miles as a total area of the watershed of the Ohio River above the present intake opposite the city.

TABLE 129.—*Table showing the monthly rainfall in inches at various stations in the Ohio River Valley for the year 1898.*

Station.	Jan	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Tots
Cincinnati, Ohio	7.76	2.21	6.70	1.15	3.03	1.58	3.26	2.61	2.62	2.90	2.69	2.46	38. 7
Portsmouth, Ohio	10.03	1.69	5.14	2.05	3.53	3.13	5.27	6.92	1.97	3.59	2.54	2.76	48. 2
Catlettsburg, Ky	8.05	2.48	6.93	2.19	4.83	4.52	4.84	6.93	2.10	4.14	2.65	2.83	52. 9
Point Pleasant, W. Va	8.04	1.93	5.81	1.48	3.51	2.87	2.79	6.40	2.07	3.15	2.67	2.57	43. 9
Parkersburg, W. Va	5.73	2.24	5.43	2.17	2.76	4.98	4.38	4.66	2.09	3.90	2.50	2.16	43. 0
Marietta, Ohio	5.74	2.39	6.03	2.30	2.77	5.04	5.20	5.31	3.69	4.24	3.15	2.21	48. 9
Wheeling, W. Va	4.79	2.50	5.15	3.72	3.63	2.98	5.81	7.82	3.24	3.37	2.66	3.03	48. 3
Pittsburg, Pa	3.40	1.60	5.45	1.60	3.99	3.98	2.56	4.01	1.06	3.85	2.34	1.90	35. 4
Oil City, Pa	5.32	2.53	5.74	2.13	4.64	4.56	4.45	6.73	2.11	5.18	4.33	2.90	50. 2

TABLE 130.—*Table showing the normal monthly rainfall in inches at various stations in the Ohio River Valley.*

Station.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Tot
Cincinnati, Ohio	3.5	3.7	3.3	3.2	3.4	4.4	3.4	3.7	2.4	2.4	3.3	3.2	38 9
Portsmouth, Ohio	3.5	3.2	3.5	3.2	3.5	4.0	3.9	3.4	2.8	2.8	2.9	3.5	40 2
Catlettsburg, Ky	4.3	4.0	4.2	3.2	4.0	3.8	4.4	3.6	2.9	2.7	3.5	2.9	4 5
Point Pleasant, W. Va	3.5	4.1	3.9	3.7	3.5	4.2	4.4	4.0	2.4	2.4	3.1	2.7	4 9
Marietta, Ohio	3.1	3.1	3.2	3.3	3.9	4.1	4.4	3.9	3.1	3.1	3.1	3.4	4 7
Parkersburg, W. Va	3.9	3.8	3.0	3.2	3.5	4.0	4.4	3.8	3.1	2.3	2.8	2.3	40 1
Wheeling, W. Va	3.4	3.1	2.6	2.8	4.1	3.7	3.7	4.1	2.8	2.6	2.7	3.0	3 6
Pittsburg, Pa	2.6	2.5	2.8	3.0	3.5	3.6	4.0	3.4	2.9	2.8	2.6	2.9	3 6
Oil City, Pa	3.3	3.6	2.8	2.7	3.9	4.6	3.6	2.7	3.4	2.6	3.2	2.8	3 2

COMPARISON OF THE FREQUENCY, INTENSITY, AND DURATION OF RISES OR FLOODS IN THE OHIO RIVER AT CINCINNATI DURING 1898 WITH THE NORMAL.

This subject is one of great importance from a practical standpoint, because it deals with factors which directly produce the large quantities of and variations in the matters suspended in the river water. In view of the fact that these suspended matters are a point of vital significance in connection with the construction of an applicable system of clarification and purification, and also in the efficiency and economy of its operation, it is necessary to know, at least in general terms, how nearly normal was the suspended matter during these tests, and further, it would be very desirable to be able to foretell the conditions with regard to the suspended matters due to rises, as an aid in the operation of a plant.

To accomplish these purposes involves a study of the frequency, intensity, and duration of the rises in the river. It is an easy matter to deal with the first of these factors, except when the rises overlap each other; but to establish a relation between suspended matter, both in amount and character and the intensity and duration of rises, is a very difficult and perplexing problem. At the beginning of a freshet the rapidity with which the water rises seems to be a great factor, and the more rapid is the rise the greater is the amount of suspended matter and also the percentage of silt. When the rise is of a long duration it is found that, with the waters coming from the head of the valley, the weight of suspended matters gradually decreases, but the percentage of clay steadily increases, owing to the deposition of silt in the stream itself.

Just how it is best to arrange the available data to throw light upon these points is not wholly clear to us, since all efforts in this direction are wholly arbitrary and of necessity incomplete. However, it is believed that a comparison of the intensity and number of rises in the river with the rises for the past ten years will give as good a comparison for this purpose as can be obtained. In the following table, therefore, are given the number of days on which the river was rising moderately, rapidly, very rapidly, and when there was developing an extreme freshet:

TABLE 131.—*Number of days in the year on which the Ohio River was rising at various rates during the last ten years.*

Year.	Rate of rise in feet per day.			
	1.0–2.9.	3.0–5.9.	6.0–11.9.	Over 12.
1889	66	12	3	0
1890	63	31	4	0
1891	44	24	4	0
1892	33	10	5	1
1893	34	23	2	0
1894	24	8	4	0
1895	26	11	5	1
1896	47	24	2	0
1897	45	21	2	1
1898	54	25	7	0
Average	44.6	18.9	3.6	0.3

TABLE 132.—*Summary of amounts of the several constituents found in water of Ohio River during the year 1898.*

Constituent.	Parts per million.		
	Maximum.	Minimum.	Normal.
Total suspended matter	2,333.0	24.0	230.0
Suspended organic matter (nitrogen as albuminoid ammonia)	0.758	0.022	0.200
Total dissolved residue	223.0	67.0	120.0
Total nitrogenous organic matter	0.868	0.106	0.290
Nitrogen as free ammonia	0.074	0.008	0.025
Nitrogen as nitrites	0.030	0.000	0.003
Nitrogen as nitrates	1.34	0.37	0.60
Chlorine	44.0	3.0	10.0
Sulphuric acid	46.0	13.0	24.0
Normal hardness	57.0	11.0	33.0
Alkalinity	70.0	20.0	45.0
Microscopic organisms per cubic centimeter	40.0		
Carbonic acid	47.0	6.0	26.0
Bacteria per cubic centimeter	150,000	1,000	20,000

Odor.—The river water ordinarily has a slight odor characteristic of surface waters, the nature and intensity of which are somewhat variable. At different times the odor is musty, aromatic, resinous, and vegetable. The latter is most noticeable after heavy rains during the warm portions of the year. These odors become more pronounced upon heating the water, but, so far as noted during these tests, there is a practically complete absence of disagreeable or objectionable odors.

Color.—Independent of the suspended matter in it the normal river water is practically colorless, although in absolute terms it contains a small but measurable amount of color. It seems quite probable that, at times following certain kinds of rises in the river, there is an appreciably larger amount of dissolved color in the water than is normally the case; but experience shows that ordinarily it is easier to remove the unusual amounts of dissolved color than is the case with the finest particles of suspended clay. After passage through a Pasteur filter or a fine paper filter the water contains no color which is ordinarily visible.

Taste.—Ordinarily the river water has an earthy taste, which, however, does not become disagreeable except at times of great turbidity. Freed of its suspended matter, this water has a very satisfactory and agreeable taste.

Appearance.—The turbidity of the river water is such that its appearance is almost always unsatisfactory and uninviting, and for about half of the time it is so turbid that it is repulsive when considered for domestic use.

Weight of suspended matters.—When expressed in parts by weight per million parts of water by volume, the suspended matters in this water normally range from 20 to 2,500 and average about 230 parts.

Character of suspended matters.—In character as well as in amount of suspended matter the river water possesses a wide and rapidly changing degree of variability. The water in the course of the year contains an almost endless combination of varying proportions of fine sand made up of particles of quartz and hard silicates, with high specific gravity and a diameter larger than 0.002 inch; of silt with its intermediate size, specific gravity, and composition; and of very fine clay particles of aluminum silicate, with varying degrees of hydration, of low specific gravity, and of a size ranging from 0.0002 inch to less than 0.00001 inch.

Amount of organic matter.—The organic matter in the river water ranges from an amount which is fairly normal for Eastern waters to quantities (during rises) which are excessive, as judged by the data for many years collected from rivers not located in this general section of the country. The local data summarized above are a striking proof of the fact that it is not the amount but the character of the organic matter which is of importance from a sanitary standpoint.

Character and stability of organic matter.—From the immediately adjoining portion of the watershed there is quite an amount of sewage pollution. Owing to the large dilution, the deleterious effect of this is greatly attenuated. By no means is it eliminated at times of comparatively clear water, but during rises this crude organic matter to a considerable degree seems to be united and attached to particles of suspended matter, and thus carried to the bottom.

The consequence of this dilution and sedimentation is that the water contains very little organic matter, except that of a fairly stable character coming from the washings of the surface of the earth. With water taken from the new intake, above the local sources of pollution, this will be true to a still greater degree.

Alkalinity.—The alkalinity is caused by the carbonates and bicarbonates of lime and magnesia, and in a measure corresponds to temporary hardness (bicarbonates). It is the alkalinity which measures the capacity of the water to decompose sulphate of alumina and other coagulating salts. This water contains an average and minimum alkalinity of 45 and 20 parts per million, respectively. By these amounts of alkalinity there can be decomposed, respectively, about 6.5 and 3 grains per gallon of sulphate of alumina of ordinary composition, assisted by the average absorption of chemical by the suspended matters in the water.

Incrusting constituents.—Those constituents of water which produce incrustations in steam boilers comprise the sulphates, chlorides, and perhaps nitrates of lime and magnesia. In this water they are present (on an average of 33 parts per million) to a degree greater than in most of the Eastern waters, but smaller than in the waters farther west. On the whole, this water is a good one for boiler purposes, so far as incrusting constituents are concerned.

Gaseous constituents.—Atmospheric oxygen is apparently present in this water during cold weather to about the limit of saturation, and during the warm season there is contained in the water rather more oxygen than is the case with some surface waters, although the quantity at times becomes only about 40 per cent of that found during the winter. Carbonic acid (carbon dioxide) is present in this water to a degree which is apparently high, according to the limited data available from Eastern sources, but much lower than is the case with waters farther west coming from limestone regions.

Taking together atmospheric oxygen and the carbonic acid, they make the natural conditions quite favorable for the corrosion of unprotected iron receptacles, but the corrosion of lead pipes is promptly arrested by the action of dissolved constituents of the water itself.

Numbers and kinds of bacteria.—On an average the numbers of bacteria in the

river water (about 20,000 per cubic centimeter) are rather higher than in the ordinary river water. The range is also very great, 1,000 to 150,000, and is associated very intimately with the rises of the river.

At the present point of intake, opposite the city, a considerable number of the bacteria are of sewage origin. These sewage bacteria will be largely absent apparently in the water taken from the new intake at California.

Microscopic organisms.—The turbidity of the Ohio River water was so great during the larger part of the year 1898 that the sunlight was excluded to a degree practically inhibiting the growth of algæ and similar micro-organisms. When the river water was low and fairly clear these organisms were present in considerable numbers, but did not become of practical significance. The dissolved constituents (such as nitrates) in the river water, and especially at times of low water, are well adapted, however, as a food for the organisms which also require sunlight for their development.

TABLE 133.—*Suspended matter in water of Ohio River at Cincinnati from January 10 to March 23, 1898, with corresponding stages of height of river in feet.*

[In parts per million.]

Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	Suspended matter.	Date.	Stage of river.	Suspended matter.
Jan. 10	33.0	2,333	Feb. 3	25.0	372	Feb. 24	33.0	221
11	32.2	1,151	4	21.5	184	25	33.2	332
12	35.4	1,024	5	18.7	134	26	32.4	170
13	38.0	719	6	16.5	113	27	30.7	123
14	37.7	578	7	14.7	108	28	28.0	141
15	39.7	470	8	14.0	96	Mar. 1	25.0	150
16	42.5	433	9	13.4	88	2	27.6	43
17	44.3	416	10	13.0	172	4	18.7	125
19	44.5	308	11	13.7	237	5	17.5	114
21	45.5	358	12	16.2	401	8	15.4	57
22	44.4	285	13	17.3	377	12	16.3	393
23	49.7	401	14	19.5	182	15	17.6	102
24	50.4	535	15	23.5	425	16	19.0	174
25	51.3	522	16	27.6	262	17	22.6	406
26	52.2	601	17	30.0	246	18	25.2	684
27	51.2	533	18	31.4	236	19	28.6	300
28	49.3	292	19	30.7	192	21	41.0	782
29	47.1	269	20	31.1	413	22	42.3	479
30	43.5	207	21	30.5	293	23	46.7	476
31	39.1	57	22	30.6	149			
Feb. 2	29.5	248	Feb. 23	30.6	310			

Of great importance as evidence of sewage pollution were the tests for Bacillus coli communis, which, as stated in previous pages, is an intestinal parasite. Mr. Fuller found that there was little room for

doubt that this germ was constantly present in the river water. He states:

From the evidence at hand it is probable that, by taking 2 cubic centimeters for each test, this germ would be found practically without exception. Upon taking 1 cubic centimeter for each test the identity of this bacillus was established in 60 per cent of the samples as shown by the results of tests, as follows:

TABLE 134.—*Result of tests (positive and negative) for Bacillus coli communis in Ohio River water at Cincinnati.*

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
1898.		1898.		1898.		1898.	
Mar. 24	–	May 2	+	June 7	+	Aug. 1	+
25	–	3	+	9	–	2	–
26	–	5	+	10		3	+
29	+	6	+	13	–	5	+
31	+	7	–	15	+	6	+
Apr. 1	–	8	–	16	+	7	+
2	–	9	+	18	–	9	
3	–	10	+	19	+	10	+
4	–	11	+	20	+	12	+
5	+	12	+	24	–	13	+
6	+	13	–	25	+	15	+
7	–	14	+	28	–	16	+
8	+	16	+	29		18	+
9	+	17	+	30	–	19	
10		18	–	July 1	–	20	+
11	–	19	+	2	–	22	–
12	–	20	–	4	–	23	
13	+	21	–	7	–	24	+
14	–	22		8	+	27	+
15	+	23	–	9	–	30	
16	+	24	+	10	+	31	+
17	–	25		13	+	Sept. 2	+
18	+	26	+	14	–	3	–
20	+	27	+	16	+	5	–
21	–	28	+	18	–	9	–
22	+	29		19	+	10	–
23	+	30	–	20	+	13	+
25	+	31	+	22	–	14	
26	–	June 1	–	23	+	15	–
27	–	2	–	25	–	16	–
28	–	3	+	27		17	+
29	+	4	–	28	+	18	
30	+	6	+	29	+	21	–

TABLE 134.—*Result of tests (positive and negative) for Bacillus coli communis in Ohio River water at Cincinnati*—Continued.

Date.	Result.	Date.	Result.	Date.	Result.	Date.	Result.
1898.		1898.		1898.		1898.	
Sept. 22	+	Oct. 15	+	Nov. 7	+	Dec. 2	—
23	+	17	—	8	+	3	—
26	+	19	—	10	—	6	—
27	+	20	—	11	—	8	+
29	+	22	—	12	—	10	—
Oct. 1	+	23	—	16	—	13	+
3		24	+	17	+	15	+
5	+	27	+	19	—	17	+
7	—	28	+	20		20	+
9	+	28	+	21		21	+
10	+	30	+	24		24	+
11		Nov. 1	+	26	+	27	—
13	+	2	+	28	—	29	—
14		4	+	30	—		

MIAMI AND LITTLE MIAMI RIVERS.

The important tributaries entering the Ohio next below Scioto River are Miami and Little Miami rivers. They occupy the most elevated portions of Ohio, and the drainage basin of the larger river extends into Indiana. Taken altogether, the area drained by the two rivers covers 6,950 square miles, of which 5,601 lie in Ohio. (See fig. 17.) The population in the basin is 641,657, or about 92 per square mile. Thirty cities and villages, representing a population of 242,762, have water supplies. This is 91 per cent of the urban population in the river basin and 44 per cent of the entire population. Fifteen of the cities have been supplied with sewerage systems, all of which discharge into the neighboring streams without previous purification.

LITTLE MIAMI RIVER.

The drainage basin of the Little Miami River occupies a small, wedge-shaped portion of the State of Ohio lying between the basins of the Scioto and Miami rivers and fronting at the broad southern end on Ohio river. From its headwaters to its confluence with the Ohio the Little Miami traverses 94 miles and has a total fall of 696 feet, or 7.4 feet per mile. The tributaries of the Little Miami are Cæsars Creek, Todds Fork, and the East Branch of the Little Miami, the latter, draining an area of 475 square miles, being the most important.

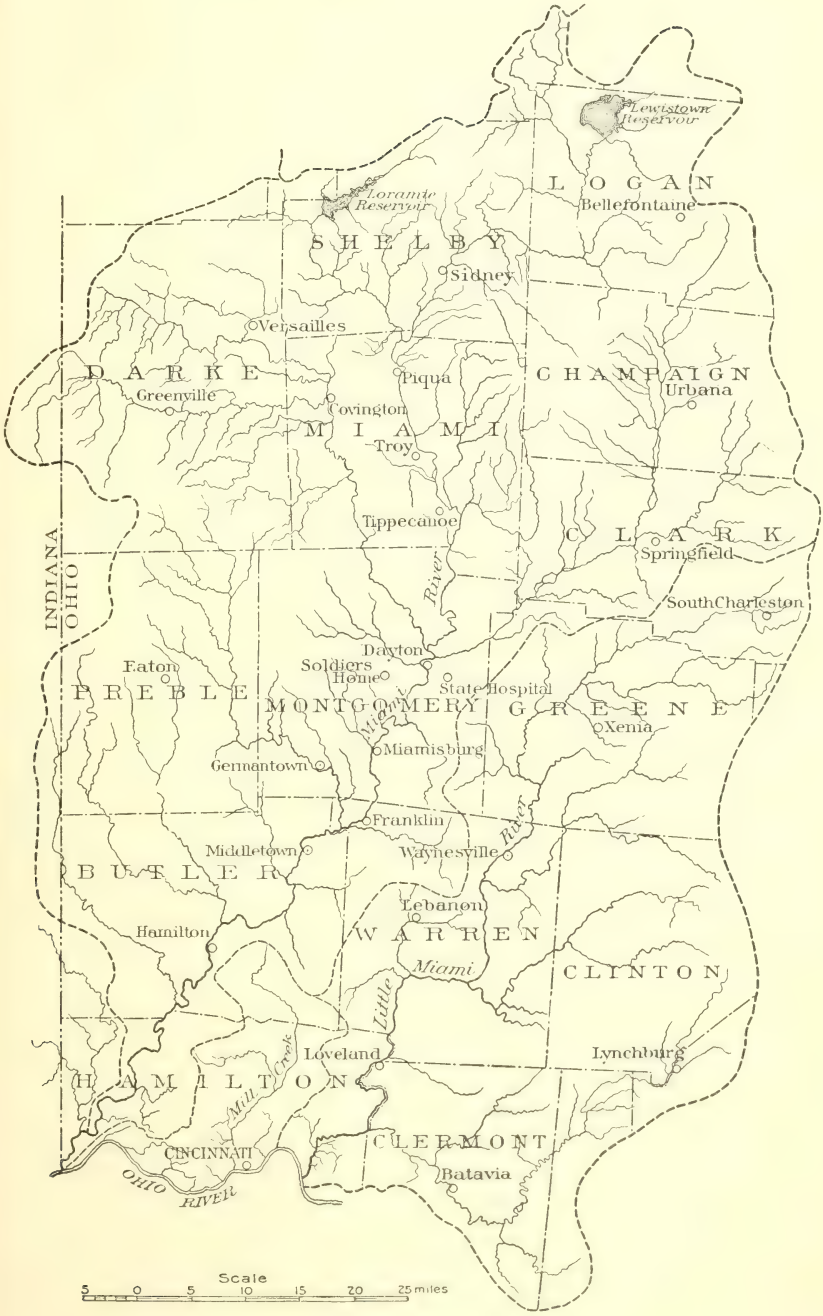

FIG. 17.—Drainage basins of Miami and Little Miami rivers.

The drainage area of the Little Miami is almost entirely devoted to farming. It is a prosperous country, with a rural population of 81,314 and an urban population of only 39,645. Sewage pollution from cities is, therefore, not so important here as in other areas which have been studied; but the run-off water from highly fertilized fields shows on analysis a large proportion of organic constituents which, if interpreted from the analysis alone, without special acquaintance with the origin of the water, would perhaps indicate a high degree of sewage pollution.

At the headwaters of the river, in Clarke County, the first important settlement is South Charleston, which has a population of 1,096. There are three short sewers in the village, and the water supply is from private wells 15 to 20 feet deep. South Charleston can therefore be considered the head of pollution upon Little Miami River. Above this place the waters are probably free from specific sewage contamination. Analyses show, however, that the organic matter is extremely high, due undoubtedly to the run-off from manured fields and rank decay of vegetable growths.

TABLE 135.—*Analyses of water from Little Miami River above South Charleston.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
May 28	47	26	e[a]	0.200	0.138	0.042	1.24	.....	354	225.8	66.0	3,800	0.72
June 26	144	40	v	.442	.262	.090	.66	.....	390	239.4	39.8	2,200	.80
July 17	120	30	v	.522	.230	.022	.06	1.5	438	290.2	7.4	3,800	.74
Aug. 20	130	30	e	.540	.156	.018	.....	0.0	349	221.8	36.2	2,800	1.59
Oct. 18	95	23	v	.242	.080	.013	.000	0.0	362	223.2	00.0	3,400	.03
Nov. 7	100	29	v	.356	.112	.018	.000	4.0	423	266.2	00.0	3,000	.23

[a] e, earthy; v, vegetable.

The analyses set forth in the above table indicate a water of comparatively high organic content. The testimony of the free ammonia and nitrite determinations would seem to indicate a fairly high degree of sewage pollution, but this is not borne out by the remainder of the analytical statement. The water can not be regarded in any sense as normal, but it is probably free from dangerous impurities.

Below South Charleston, on Little Miami River, are Clifton and Yellow Springs, with populations of 262 and 1,371, respectively, producing no appreciable contamination of the surface drainage.

On Massicks Creek, which enters the Little Miami just above Xenia,

are situated Cedarville and Wilberforce College. At the former place a strawboard works contributes the usual amount of deleterious matter, while at the college a part of the plumbing system is connected with the creek.

The water which comes down to Xenia in the channel of Little Miami River has received the pollution from several unimportant settlements, but most damaging refuse comes from the strawboard works at Cedarville. Analyses of the water (see Table 136) indicate that, from a chemical standpoint, it is of as good quality as that found at the headwaters, above artificial pollution. The bacteriologic examination, however, is indicative of an organic content more highly putrefactive than that which was present in the water above South Charleston.

TABLE 136.—*Analyses of water from Little Miami above Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Rainfall during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 26	45	20	v[a]	0.220	0.032	0.028	1.17	1.1	335	223.8	18.4	44,000	0.96
May 28	80	28	v	.270	.230	.034	.70	.5	396	234.8	27.8	120,000	1.35
June 28	175	33	v	.314	.174	.038	.67	.8	423	250.8	00.0	4,800	.93
July 17	142	30	v	.794	.280	.056	.03	.7	374	260.8	00.0	1,700	.38
Aug. 22	110	43	v	.296	.090	.030	.02	.0	369	230.2	22.2	17,000	2.92
Sept. 17	50	16	v	.226	.066	.022	.06	1.4	315	235.8	00.0	3,200	.18
Oct. 18	48	35	M	.302	.136	.009	.0	.8	386	269.8	00.0	180,000	.05
Nov. 9	28	65	v	.306	.006	.010	.12	1.9	368	287.2	00.0	80,000	.23

[a] v, vegetable; M, musty.

Below Xenia the water of the Little Miami does not seem to be inferior to that above. Although the city has a population of 8,696, no sewers have been established, and the contamination of the river is not so great as might be expected from a municipality of this size. Xenia is not situated directly upon Little Miami River, but some distance up a small stream called Shawnee Run. The greatest source of pollution about Xenia is the Ohio Soldiers and Sailors' Orphans' Home, situated on Shawnee Run, southeast of Xenia. This home has an average population of 1,010, and has its own water supply and sewerage system connected with the stream.

TABLE 137.—*Analyses of water from Little Miami River below Xenia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per cubic centimeter.	Rainfall during previous 10 days.
1901.													*Inches.*
Apr. 26	45	26	v[a]	0.286	0.020	0.032	1.28	1.6	362	240.2	13.8	62,000	0.96
May 28	87	32	v	.292	.310	.058	.89	4.3	418	254.4	7.0	12,000	1.35
June 28	175	33	v	.328	.180	.036	1.04	2.2	383	221.6	32.0	5,100	.93
July 17	105	28	v	.314	.142	.032	.36	3.2	375	256.6	.0	1,200	.38
Aug. 22	90	38	v	.462	.070	.030	.00	.0	344	236.6	.0	177,000	2.92
Sept. 17	55	17	v	.282	.078	.022	.00	1.9	388	242.4	.0	2,600	.18
Oct. 18	54	33	M	.212	.134	.009	.00	1.7	380	252.4	.0	34,400	.05
Nov. 9	35	58	v	.324	.050	.010	.10	1.6	378	281.0	.0	148,000	.23

[a] v, vegetable; M, musty.

Proceeding down the river from Xenia, the most important points of pollution discovered are Waynesville, having a population of 723; Wilmington, on Todds Fork, inhabited by 3,613 people; Blanchester, on the same tributary, with 1,788 inhabitants; Lebanon, on Turtle Creek, with 2,867, below which is Loveland. At this point a series of examinations has been made by the State Board of Health of Ohio, the results of which are reproduced in Table 138.

TABLE 138.—*Analyses of water from Little Miami River above Loveland.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per cubic centimeter.	Precipitation during previous 10 days.
1901.													*Inches.*
Apr. 24	40	18	v[a]	0.216	0.036	0.011	1.26	1.0	316	194.2	20.2	1,800	0.45
May 29	430	30	e	.332	.076	.018	.52	.8	483	157.6	15.2	21,000	1.67
June 26	250	15	m	.324	.096	.009	.40	2.2	389	238.8	12.4	1,500	.00
July 17	235	13	v	.254	.066	.026	.30	2.6	350	219.6	11.2	1,200	.39
Aug. 20	800	33	e	.312	.124	.024	.31	.0	338	128.2	20.6	8,000	.86
Sept. 17	103	20	e	.321	.036	.006	.00	2.8	316	210.0	.0	1,900	.00
Oct. 19	90	18	v	.220	.032	.006	.00	2.9	378	224.0	.0	2,100	.00
Nov. 9	60	26	e	.176	.022	.010	.00	2.7	343	221.2	.0	1,400	.27

[a] v, vegetable; e, earthy; m, moldy.

The analyses above set forth, when compared with those in tables 135, 136, and 137, indicate a considerable improvement in the general character of the water. Free ammonia and nitrites, which are indicative of sewage pollution, are present in the Loveland water in smaller proportion than in water taken higher up in the drainage area. The chlorine content, however, maintains the same high proportion, and is

an evidence of the contaminating influences of the municipalities above mentioned.

EAST FORK OF LITTLE MIAMI.

Below Loveland enters the East Branch of Little Miami River, the principal centers of population on which are Lynchburg and Batavia. At the former place a surprisingly large amount of refuse is discharged into the stream from a distillery and from numerous drains which lead out of the town. At Batavia a public water supply has been established and a number of storm sewers conduct surface drainage into the stream. Tables 139 and 140 are reports of analyses made by the Ohio State Board of Health, which fairly indicate the character of the water above and below Batavia.

TABLE 139.—*Analyses of water from the East Fork of Little Miami River above Batavia.*

[Parts per million.]

Date of collection.	Turbidity	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 25	65	25	e[a]	0.300	0.044	0.001	0.03	2.1	270	154.8	39.0	3,200	0.65
June 1	95	33	v	.372	.018	.006	.14	.5	258	160.8	42.0	.....	1.49
June 27	70	25	v	.296	.148	.002	.12	.5	257	149.4	23.4	750	.77
July 20	86	25	m	.310	.118	.010	.04	.0	251	167.6	.0	2,100	1.71
Aug. 21	900	28	e	.332	.086	.012	.00	.0	307	80.0	.0	40,000	1.69
Sept. 19	116	23	v	.398	.060	.003	.00	1.1	238	135.4	50.2	2,300	.00
Oct. 19	165	28	v	.268	.035	.003	.00	2.2	251	111.4	10.2	5,400	.00
Nov. 8	70	28	v	.330	.034	.002	.08	4.6	233	121.8	6.8	1,500	.33

[a] e, earthy; v, vegetable; m, moldy.

TABLE 140.—*Analyses of water from East Fork of Little Miami River below Batavia.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 25	60	25	e[a]	0.350	0.052	0.002	0.02	2.4	299	157.6	63.8	3,500	0.65
June 1	95	33	v	.348	.032	.007	.16	1.1	277	161.2	19.4	.....	1.49
June 27	70	28	v	.266	.146	.010	.13	.9	261	143.2	73.8	1,300	.77
July 20	80	25	v	.302	.136	.010	.03	.9	262	195.2	.0	2,200	1.71
Aug. 21	800	28	e	.314	.104	.013	.00	.0	353	80.2	8.2	38,000	1.69
Sept. 19	110	23	v	.326	.102	.005	.00	1.8	246	139.0	.0	1,500	.00
Oct. 19	165	32	v	.234	.020	.005	.00	3.0	243	115.0	.0	6,000	.00
Nov. 8	65	25	M	.276	.034	.002	.04	4.4	230	124.4	23.2	2,300	.33

[a] e, earthy; v, vegetable; M, musty.

From the confluence of the East Branch the Little Miami flows southward and empties into the Ohio just above the city of Cincinnati. From the mouth of the East Branch to the confluence of the river with the Ohio the pollution is insignificant. Analyses of the water below Linwood, a suburb of Cincinnati, make it appear preferable to any reported from the drainage area above.

TABLE 141.—*Analyses of water from Little Miami River, below Linwood.*

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1901.													*Inches.*
Apr. 24	35	13	v[a]	0.192	0.042	0.010	0.57	2.6	308	190.6	19.4	6,100	0.45
May 29	+3,000	25	e	.638	.097	.010	.18	0.5	1,529	106.6	26.4	30,000	1.67
June 26	187	23	v	.260	.118	.006	.08	3.2	345	212.8	3.0	3,000	.00
July 19	+3,000	25	e.	.658	.134	.014	.10	1.3	1,913	127.6	25.2	43,000	1.53
Aug. 20	1,000	28	e	.246	.068	.022	.10	0.0	352	108.2	.0	7,300	.86
Sept. 18	120	23	e	.370	.076	.006	.00	3.4	326	205.8	.0	1,300	.00
Oct. 13	200	32	e	.302	.064	.006	.00	3.1	356	161.6	.0	3,900	[b]1.12
Nov. 8	40	25	e	.202	.026	.000	.04	4.1	302	229.2	8.6	1,200	.27

[a] v, vegetable; e, earthy. [b] Storms one week previous.

The drainage basin of Little Miami River is without special interest from the standpoint of water pollution. As has already been observed the urban population is comparatively small and the sewage it contributes to the river does not seem to have very marked effects on the water. The analyses show a high content of organic matter from the headwaters down, and while the water may not have been much damaged it is certainly not so desirable for public use as some of the purer waters found in other parts of the State. It can hardly be said, however, that Little Miami River has suffered greatly from city or manufacturing refuse, and it is more than likely that if all sewage were removed from the stream and its tributaries the natural drainage of an area so highly fertilized would so change the character of the run-off water that it would be hardly acceptable for city water-supply purposes without filtration. The other resources vested in the natural waters of this area do not appear to be damaged appreciably.

MIAMI RIVER.

Entering Ohio below Cincinnati, the Miami River drains a basin to the north thickly dotted over with towns and cities. The main stream is formed at Dayton by the confluence of the Upper Miami, Stillwater, and Mad rivers, which have drainage areas of 1,158, 645, and 653 square miles, respectively. From Dayton to the mouth the river flows in a somewhat winding course to the southwest. From its

headwaters in Lewistown reservoir, in the extreme northern part of the drainage area, to its mouth the Miami has a length of 163 miles.

NORMAL WATER IN THE MIAMI BASIN.

In a drainage area like that of the Miami it is difficult to secure samples of normal water. The run-off from land given over to agriculture is seldom, if ever, of a quality which approaches the normal very closely. There appear, however, in the report of the Ohio State Board of Health for 1901 three series of analyses of water taken from streams which, so far as is known, bear no direct sewage pollution. These streams are Mad River above Urbana, Buck Creek, a tributary of Mad River, above Springfield, and Greenville Creek above Greenville City. The population upon the drainage area of these streams above the points named is of the usual agricultural nature, and the pollution of the run-off water is probably confined to the drainage of manured fields.

The analyses made by the Ohio State Board of Health are set forth below in Table 142.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin.*

BUCK CREEK ABOVE SPRINGFIELD.

[Parts per million.]

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.	Precipitation during previous 10 days.
				Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.		
1900.													*Inches.*
Apr. 16	.....	10	None	0.104	0.016	0.005	0.84	0.4	407	242.0	2.98	325	0.54
May 24	25	10	v[a]	.328	.032	.010	1.14	.3	431	244.0	27.20	1,200	1.49
June 20	32	23	e	.096	.036	.008	.83	.2	438	268.0	12.00	375	.00
July 10	90	15	e	.176	.028	.010	1.06	.4	463	260.2	30.00	800	.33
Aug. 9	57	17	v	.134	.042	.010	1.64	.0	384	227.6	29.00	400	.00
Sept. 5	60	13	v	.206	.044	.011	1.46	.0	386	239.4	1.80	600	.40
Oct. 3	35	15	v	.112	.022	.002	1.63	.4	425	219.4	3.00	1,200	1.63
Nov. 3	16	17	None	.078	.019	.014	2.12	.5	399	249.4	13.20	1,000	.23

MAD RIVER ABOVE URBANA.

1900.													*Inches.*
Apr. 19	100	32	e	0.258	0.014	0.010	1.87	0.0	497	229.0	60.6	12,000	1.42
May 24	17	12	e	.104	.040	.010	.82	.5	347	265.4	3.0	700	.86
June 20	70	21	v	.170	.050	.009	.83	.0	434	271.8	26.8	1,700	.00
July 9	100	18	v	.220	.060	.017	.64	.2	410	266.2	11.4	2,200	1.05
Aug. 9	95	22	v	.182	.054	.016	1.04	.2	396	250.4	.0	3,300	.11
Sept. 5	165	28	e	.380	.032	.007	.83	.0	438	230.4	21.0	5,900	.25
Oct. 3	90	18	v	.130	.032	.006	1.26	1.0	462	260.2	1.6	4,000	1.31
Nov. 3	28	20	None	.086	.019	.005	.00	.0	390	251.4	1.4	2,200	.20

[a] v, vegetable; e, earthy.

TABLE 142.—*Analyses of nearly normal waters in the Miami River Basin*—Cont'd.

GREENVILLE CREEK ABOVE GREENVILLE.

Date of collection.	Turbidity.	Color.	Odor.	Nitrogen as— Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.	Chlorine.	Total residue.	Hardness. Alkalinity.	Normal hardness.	Bacteria per cubic centimeter.	Precipitation during previous 10 days.
1900.													*Inches.*
Apr. 17	28	20	v[a]	0.188	0.030	0.016	3.44	0.2	449	217.8	83.0	3,300	0.60
May 22	24	28	v	.211	.094	.038	2.09	.0	380	226.2	40.0	1,100	1.22
June 18	28	25	v	.184	.084	.014	.55	.6	467	278.4	31.0	1,300	.00
July 10	70	27	v	.214	.060	.020	.44	.4	369	280.0	.0	1,100	.52
Aug. 7	65	22	v	.268	.134	.011	.00	2.7	421	255.4	3.2	2,000	1.68
Sept. 3	55	23	v	.186	.096	.010	.00	1.0	413	269.0	.0	4,700	.00
Oct. 1	120	42	v	.272	.063	.024	2.12	.0	432	189.6	35.0	19,000	3.22
Nov. 1	28	20	e	.164	.019	.002	.00	1.5	472	274.0	26.6	6,400	.35

[a] v, vegetable; e, earthy.

Inspection of the above table readily shows that the water in Buck Creek above Springfield is decidedly the best. Throughout the whole table the content of organic matter indicated is comparatively low and maintains a fair degree of uniformity. In the Buck Creek analyses the free ammonia, nitrites, and chlorine are much lower than in any analyses heretofore presented for this area. There is the same steadiness in the total residue column that was evidenced in the Little Miami examinations. Turbidity and bacteria per cubic centimeter are comparatively uniform in spite of the fact that there were wide fluctuations in the precipitation during the ten days previous to each examination.

Turning now to the three affluents of the Miami, let us consider the conditions existing within the drainage areas of each.

MAD RIVER.

Mad River has its origin in Logan County and flows with a general southwesterly trend to Dayton. The city of Urbana, with 6,808 inhabitants, lies at the head of sewage pollution. A water supply has been established in Urbana, but the sewerage system is confined to a few private lines of pipe. The principal source of pollution, however, is the highly contaminated run-off occasioned by the storage of polluting material in vaults and cesspools, rarely cleaned, but allowed to filter into the ground. The most important point of pollution is the city of Springfield, which has a population of 38,253.

Water and sewerage systems have been established, but the latter is said to be very poor, and only about 20 per cent of the population has access to it. The most flagrant source of pollution from Springfield is the method of disposing of garbage, night soil, and dead animals. These are dumped promiscuously into the river or buried on or near the banks. There is also considerable pollution from various industries.

There are available the results of analyses of series of samples

taken from Mad River above and below Urbana, above and below Springfield, and above Dayton; also from Buck Creek, above Springfield. The reports of the first and last named have already been given in Table 142.

In the following table the average results of monthly determinations at the above-named places are set forth:

TABLE 143.—*Analyses of water from Mad River.*

[Averages for eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Urbana	80	21	0.191	0.038	0.010	0.91	0.2	422	253.1	14.5	4,000
Below Urbana	115	47	.608	.039	.060	.47	1.2	456	278.7	16.5	160,000
Above Springfield	80	27	.260	.076	.028	.48	.5	431	272.1	12.1	9,500
Above Springfield (Buck Creek)	40	15	.154	.030	.009	1.34	.3	417	243.8	18.2	738
Below Springfield	75	24	.270	.201	.042	.60	3.3	435	270.6	9.2	31,000
Above Dayton	80	20	.194	.033	.011	1.32	2.8	417	254.8	14.0	6,750

Inspection of the above analyses shows the usual unmistakable evidences of contamination of the river from the two principal polluting points and the improvement of the water as it flows from one of these points to the other. The character of the water above Urbana on Mad River and above Springfield on Buck Creek has already been discussed. As the water passes by Urbana there is a notable increase in the content of organic matter as well as in turbidity and in the number of bacteria per cubic centimeter. From Urbana to Springfield the water shows undoubted improvement, but is again changed in passing the city of Springfield, while the analyses made of samples taken above Dayton show that the water has so far improved as to be, from a chemical standpoint at least, almost as good as it appears above Urbana. The Dayton samples show the character of the water contributed to the Miami system by Mad River.

UPPER MIAMI RIVER.

Upper Miami River has its origin in Lewistown reservoir and flows south by a somewhat circuitous route to join the Stillwater and Mad rivers at Dayton. The head of pollution upon the Upper Miami is Bellefontaine, a village of 6,649 inhabitants, supplied with water and a short system of storm sewers. The principal pollution from this point consists of the drainage of a few plumbing systems into the storm sewer, the refuse from slaughterhouses, and the pollution of run-off water through putrescible material stored in the ground. A few institutions, such as the Logan County Infirmary, Logan County Childrens' Home, and the Shelby County Childrens' Home and Infirmary, contribute more direct sewage pollution to the river than any of the small villages situated along the stream. The village of Sidney, having a

population of 5,688, has a water supply and has just introduced a system of sewers. These, together with a brewery and a tannery and various other incidental contaminating points, produce considerable damage to the river.

Next below Sidney is Piqua, having a population of 12,172. The public water supply at this point is not used for domestic purposes. A separate system of sewers, to which about 30 per cent of the people have access, has been established. These sewers empty directly into the Miami River. In the town are located strawboard works, oil mills, breweries, and several large slaughterhouses, and the effluent from these and the sewers is the occasion of serious nuisances at times.

Below Piqua is Troy, containing 5,581 inhabitants, and still farther down is Tippecanoe City, with 1,703. Both places have public water supplies and a few short, combined sewers, to which a small proportion of the people have access. Garbage and night soil are dumped along the river and into the Miami and Erie Canal, which flows along the river bank. In addition to the pollution from sewers, the river receives the refuse from three distilleries, two breweries, and several large slaughterhouses.

Chemical examinations of the water of the Upper Miami have been made above and below the cities of Sidney, Piqua, and Troy, and above Dayton, and the averages of the eight monthly analyses of samples taken at each point appear in the following table:

TABLE 144.—*Analyses of water from Upper Miami.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Sidney	60	23	0.295	0.066	0.009	0.52	0.7	404	219.8	33.3	1,900
Below Sidney	45	24	.289	.074	.014	.57	2.3	379	223.9	25.9	4,700
Above Piqua	290	28	.400	.077	.010	.65	1.2	484	200.6	31.9	11,000
Below Piqua	240	27	.374	.048	.027	.90	3.4	468	208.9	25.0	22,500
Above Troy	55	26	.344	.105	.018	.54	2.4	388	214.7	27.2	5,600
Below Troy	35	24	.378	.112	.019	.61	3.2	364	221.9	20.4	52,000
Above Dayton	100	25	.307	.049	.013	.68	1.5	407	220.9	24.9	5,600

The effect of sewage on the Miami River above Dayton, as indicated by the above analyses, is so obvious as hardly to merit discussion. The same general features, repeatedly observed in the discussion of drainage areas in previous pages, occur here. As the Miami enters the city of Dayton, the water, from a chemical standpoint, is only a little inferior to that in the same stream above Sidney.

STILLWATER RIVER.

Stillwater River, entering the Miami at Dayton, drains the country to the northwest, comprising large areas in Darke and Miami coun-

ties. The principal source of pollution along the entire length of Stillwater River is the city of Greenville, which has a population of 5,501. At this place water and sewerage systems have been installed, the latter being one of the best in the drainage area. In addition to the contaminating matter carried into the former from the sewers, there is the polluted surface drainage from that part of the town which has not yet been connected with the sewerage system.

In the drainage area of the Stillwater there are several institutions which furnish the usual amount of contamination. The villages of Versailles and Covington, containing 1,478 and 1,791 inhabitants, respectively, are the only remaining points within the watershed that are important from the standpoint of stream pollution.

Three sampling points were selected by the Ohio State Board of Health as a basis for their investigation into the character of the water in Stillwater River. These are located above and below Greenville, on Greenville Creek, and above Dayton.

TABLE 145.—*Analyses of water from Stillwater River.*

[Averages of eight monthly examinations, in parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Above Greenville	55	26	0.211	0.072	0.017	1.08	0.8	425	248.8	27.3	4,900
Below Greenville	70	27	.274	.091	.022	1.17	2.6	475	251.7	85.4	13,500
Above Dayton	80	23	.251	.041	.009	2.02	.9	380	218.9	8.3	45,500

Examination of the results above set forth shows nothing of an uncommon nature. Above Greenville, as has been already shown in the consideration of normal waters in the Miami drainage area, there is little evidence of specific sewage contamination. Below Greenville there is, as might be expected, an increase of those ingredients whose presence is generally accepted as an indication of pollution, but the amount of this increase is not so great as might be expected when all the circumstances are considered. The analyses of samples taken above Dayton indicate the usual improvement in a water after it has flowed beyond the point of contamination for a considerable distance.

The city of Dayton has a population of 85,333, the largest on the drainage area of the Miami. It is provided with a water supply and a sewerage system, to which 30 per cent of the people have access. Garbage is burned in a crematory and night soil is disposed of upon the farms outside the city, so that the pollution of the river is confined to the affluents from the sewerage system and the refuse turned into the stream by industrial plants, which consist of breweries, slaughter and packing houses, oil mills, soap works, and paper and strawboard manufactories.

MIAMI RIVER BELOW DAYTON.

Below the city of Dayton, on the Miami, are located the National Soldiers' Home and the Dayton State hospital. The combined population of these two institutions is 5,810. Both are provided with sanitary sewers and improved systems of plumbing, which discharge directly into the river. This is the largest center of pollution in the whole drainage area, greater, in fact, than the city of Dayton itself. Continuing down the river from the two institutions above mentioned, the next important point is Miamisburg, which has a population of 3,941. Industrial pollution seems to be the most important at this village, which has no water or sewerage system.

The village of Franklin, a few miles below Miamisburg, is inhabited by 2,724 persons and is supplied with water and a small system of sewerage. In addition to the contamination afforded by the latter, a large proportion of the garbage of the town is dumped into the river and some of the industrial plants, such as paper mills and slaughter-houses, pour their refuse into the stream.

Middletown is situated a few miles below Franklin, on the east bank of Miami River. It has an excellent water supply and sewerage system, through which the sewage of about 2,000 persons is carried directly into the river. The waste from a large number of manufacturing establishments also finds its way there. Among these are gas works, breweries, malt houses, etc.

A few miles below Middletown is the city of Hamilton, through the center of which Miami River passes. Hamilton has a population of 23,914, a good water supply, and an extensive system of sanitary and storm sewers. In addition to the polluting material poured into the river by these sewers, it receives the refuse from a large and varied assortment of industries.

Below Hamilton there is little of interest until the mouth of the river is reached.

Sampling points selected by the Ohio State Board of Health are below Dayton, above and below Middletown, above and below Hamilton, and below Cleves.

TABLE 146.—*Analyses of water from Miami River.*

[Parts per million.]

Place of collection.	Turbidity.	Color.	Nitrogen as—				Chlorine.	Total residue.	Hardness.		Bacteria per cubic centimeter.
			Albuminoid ammonia.	Free ammonia.	Nitrites.	Nitrates.			Alkalinity.	Normal hardness.	
Below Dayton	81	25	0.309	0.067	0.021	1.99	4.2	407	220.9	24.9	65,000
Above Middletown	215	27	.261	.045	.015	.46	3.3	432	212.2	18.5	19,000
Below Middletown	257	29	.340	.047	.022	.51	5.3	461	220.5	15.4	43,000
Above Hamilton	1,820	28	.345	.058	.012	.75	3.1	626	188.7	13.9	25,500
Below Hamilton	1,300	26	.361	.072	.018	.57	4.7	551	199.4	14.5	33,000
Below Cleves	2,250	26	.406	.056	.012	.63	3.9	813	191.7	12.4	7,000

The character of the water contributed to the Ohio system by the Miami is not all that could be desired, nor indeed as good as might easily be furnished. In the course of the river from Dayton to its mouth the changes in the organic constituents of the water are not exceedingly sharp. The undesirable condition of the run-off at Dayton is maintained steadily throughout the remainder of the course. The sewage of Dayton and the two institutions just below it is apparent in the report of the analyses of samples taken above Middletown. The additional polluting material poured in from Middletown is perfectly evident, and by the time the water reaches Hamilton only a very small improvement can be noted. The water contributed to the system by the three main affluents above Dayton seems to be far superior to that which flows by Cleves into Ohio River.

OHIO RIVER AT LOUISVILLE.

During the years 1895, 1896, and 1897 extensive investigations were carried on by the Louisville Water Company to determine the character of the water in Ohio River opposite that city. Mr. George W. Fuller was placed in charge of this work, and in the year 1898 submitted an exhaustive report on the purification of the water of Ohio River. Daily examinations of the water of Ohio River were made from October 16, 1895, to July 24, 1897, the reports of which will not be given here in full, but attention will be directed to several important determinations.

Relative to the drainage area and general hydrographic conditions Mr. Fuller writes as follows:

The water of the Ohio River at Louisville varies widely from time to time in its composition. This variation is caused by a number of factors, among which are the following:

1. The size and varying geological formation of the watershed.
2. The number of comparatively large tributaries which drain areas of distinctly unlike geological character.
3. The amount of precipitation (rain and snow).
4. The distribution of the precipitation over the watershed.
5. The condition of the soil at the beginning of heavy rain storms.
6. The amount and rate of precipitation during single storms.
7. The stage of the river.
8. The velocity of flow of the river.
9. Agitation of the water in the river due to wind storms, etc.

The total population resident on this watershed above Louisville is estimated at 4,500,000, of which 1,575,000 is contained in 220 towns and cities, according to the census of 1890, increased 15 per cent for the six years of the present decade. The nearest city discharging sewage into the water which passes this pumping station is Madison, Ind., situated about 50 miles above Louisville, with a population of about 12,000. The next city is Frankfort, Ky., situated on the Kentucky River, 67 miles from its mouth. This city has a population of about 10,000. The Kentucky River joins the Ohio about 57 miles above Louisville. The nearest large center of population discharging sewage into this water supply is at Cin-

cinnati, Ohio. Opposite this city are the cities of Newport and Covington, Ky. Their aggregate population (three cities) is about 420,000, and they are distant above Louisville about 150 miles by river.

The rises and floods in the Ohio River, with their associated factors, produce wide and rapidly changing variations in the composition of the river water. Owing to the fact that the composition of the river water is a prominent factor in the cost of purification, analyses were made practically every day during these tests of the water before its application to the systems of purification. Before giving attention to the results of analyses, however, the question of frequency and depth of freshets or floods is to be considered.[a]

TABLE 147.—*Amount of carbonic acid gas (carbon dioxide) dissolved in the Ohio River water at Louisville.*

[Parts per million.]

Date.		Carbonic acid gas.	Date.		Carbonic acid gas.	Date.		Carbonic acid gas.	Date.		Carbonic acid gas.
1896.			1897.			1897.			1897.		
June	18	[b]30.8	Mar.	24	44.9	May	7	57.4	June	18	82.7
	22	[b]26.4		25	41.9		8	110.6		19	106.3
	24	[b]27.7		26	36.5		9	66.7		20	100.3
	27	[b]29.7		27	47.0		10	72.1		21	100.3
July	3	[b]30.6		29	56.6		13	65.2		22	100.3
	8	[b]21.1		30	80.0		14	76.6		23	107.4
Nov.	28	83.0	Apr.	1	53.6		15	50.8		24	100.3
Dec.	10	98.0		2	59.0		18	67.3		25	105.6
1897.				3	53.5		19	71.8		26	113.7
Feb.	16	80.4		7	79.6		21	88.7		27	120.0
Mar.	2	63.4		8	46.0		22	95.9		28	92.1
	3	59.0		9	91.0		23	94.3		30	105.9
	4	67.8		10	80.0		26	80.2	July	1	93.9
	5	49.3		12	65.0		27	80.0		2	75.3
	6	47.6		13	44.0		28	107.3		3	73.1
	7	51.4		14	75.7		29	101.6		6	100.4
	11	99.5		15	88.3	June	1	66.6		7	106.1
	12	88.0		16	50.2		2	90.5		8	99.9
	13	122.4		21	41.2		4	82.7		12	71.8
	15	45.8		22	42.7		7	89.0		15	47.0
	16	33.4		23	43.0		10	133.0		16	28.8
	19	38.8		25	55.0		11	107.6		17	49.4
	20	42.6		27	94.9		15	98.8			
	22	46.4		29	85.9		16	103.3			
	23	40.4	May	4	86.8		17	107.6			

[a] Report on the investigations into the purification of the Ohio River water at Louisville, Ky., made to the president and directors of the Louisville Water Company by George W. Fuller, 1898.

[b] The results of June and July, 1896, were obtained by the Pettenkoffer method, without the Trillich modification, and are probably much too low

The normal hardness or amount of incrusting constituents in the Ohio River water is set forth in the following table:

TABLE 148.—*Normal hardness of water of Ohio River at Louisville.*

[Parts per million.]

Date.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.	Date.	Normal hardness.
1895.		1897.		1897.		1897.	
Dec. 9–11	43.9	Mar. 15	14.0	Apr. 20–21	15.5	May 28–29	16.8
1896.		16	20.5	21–22	17.5	31	.....
May 6	43.0	17	24.6	22	12.0	June 1	17.0
14	33.8	18	36.7	22–23	14.6	2–3	17.6
22	40.1	19	16.7	23–24	14.3	4–5	23.5
29	41.1	20	22.0	27	12.7	7–8	22.5
June 11	44.0	22	12.0	28	17.0	9–10	23.8
18	30.0	23	9.6	29	32.0	11–12	28.8
July 30	35.0	24	10.8	29–30	21.7	21	28.8
1897.		25	10.0	30	.....	22	31.0
Feb. 17	18.7	26	13.9	May 1	20.0	23	27.8
22	24.7	29	12.8	4	23.0	24	21.9
23	17.2	30	33.3	5	17.0	25	19.0
24	21.2	Apr. 1	29.1	6–7	15.5	27	17.5
25	16.1	2–3	18.2	8–9	15.8	28	25.5
26	8.0	3–4	11.0	13	16.1	29–30	20.0
Mar. 1	15.8	5	29.9	14	23.2	July 2	20.0
2	10.0	6	23.4	15	11.3	6	20.9
3	8.0	6–7	30.0	17–19	9.0	7	27.0
4	12.0	8	19.8	19–20	10.8	9–10	11.0
5	25.3	9	14.2	21	11.9	12–13	12.0
6	34.6	9–10	13.3	21–23	15.9	14–15	14.8
7	16.0	11	9.0	23–24	10.2	16	14.0
9	23.4	12	12.7	25	20.2	17–18	12.3
10	17.9	13–14	16.0	25–26	14.5	19–20	24.2
11	30.0	14–15	20.0	27	16.7	21–22	24.2
12	33.0	15–16	18.1	27–28	19.3	23–24	43.8

An interesting investigation into the amount and corrosive effect of dissolved carbon dioxide in the river water brought out the fact that such determinations are of more importance than had been previously supposed. The observation is made in Mr. Fuller's report that at times the weight of the dissolved carbon dioxide in the river water equals and even exceeds the weight of all dissolved solids. The amount of carbon dioxide found in the water at each examination is set down in Table 147.

SUMMARY.

In the foregoing pages we have reviewed the important and readily available records of water examinations which have been carried on in this country, except those now being prosecuted in connection with the Chicago Drainage Canal and Illinois River. It is apparent from this review that the pollution of natural waters follows social municipal progress. Those rivers which remain in their normal condition are situated in areas that have not been penetrated to any extent by the growth of American institutions. Nearly all important streams have been damaged and their normal resources diminished. The question may be asked: Is not the damage done to these streams by the sewage of cities and by industrial plants merely a part of the compensation which we should willingly pay for the advantages that we have gained through the establishment of those polluting influences? Undoubtely, to a certain degree; but the fact still remains that in most cases when such damage is carried beyond a certain point it must be regarded as needless and unwarranted.

Water pollution is inevitable wherever the human race is clustered together in large numbers, but by the application of the methods of sewage disposal which modern science has made available, and by the exercise of an ordinary amount of municipal decency, such pollution can be so restricted that it will result in the destruction of only one or two of the resources which are vested in natural waters.

There is no doubt that the run-off water from a thickly settled country is likely to be dangerous for domestic uses unless it is filtered, and the current methods of sewage disposal, while theoretically perfect, are practically not sufficiently so to warrant us in using the so-called purified effluents as we would use the run-off from an uninhabited region. Yet, if proper precautions are taken and the same attention is paid to sewage disposal that is ordinarily given to other departments of municipal affairs, every community will be the richer and the tremendous waste of natural resources which is now taking place will ultimately be restricted to that which is necessary.

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